A Search for an Edge Image Algorithm for Application in an Automatic Registration System

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A SEARCH FOR AN EDGE
IMAGE ALGORITHM FOR APPLICATION IN
AN AUTOMATIC REGISTRATION SYSTEM

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RESEARCH REPORT

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INTRODUCTION

The electronic processing of pictures has caused the development of automatic classification methods for image content. Edge detection is a method of classification of image content. The edge is defined as a change in the average intensity or brightness in the spatial domain. Edge detection identifies the boundaries of like data within an image and may be the most significant classifier for well defined images.

The application of edge data in this case is for identifying land mass-ocean boundaries partially occluded by clouds. The use of edge detection classification significantly reduces the amount of data necessary to identify and characterize land mass. The edge detector operator will be used to provide reference features and subsequent edge images to an image correlation system for the purpose of detecting image shift between a reference image and succeeding satellite images transmitted from a meteorological satellite. The shift in image or misregistration detection and correlation is described in an accompanying report, "A Realization of a Fast Automatic Registration Algorithm for Satellite Images."
CHAPTER I

EDGE DETECTION

Edge detection is the detection of boundaries of objects in the scene. These edges can be characterized as a change in optical intensity as one scans across the boundary of an object in the scene. The edges separate regions of dissimilar texture or intensity. An example may be a satellite picture of an island in an ocean. The edge is the boundary of the island. The land mass is characterized by a difference in texture and optical intensity than the ocean. The strength or sharpness of the edge is the difference of intensity between expected pixel values within the land area and adjacent pixels in the ocean. An obvious economic benefit is that the edge may have a binary designation and the interior region may be identified by its edge elements rather than by its internal pixel elements resulting in a significant reduction in required data handling capability.

Edge detection techniques have evolved along heuristic and theoretical approaches in response to a need to classify images automatically by computer. The advent of electronic line scan-detector techniques has produced a myriad of data of which computer analysis is demanded in order to cope with the size, complexity, and timeliness of information processing. The types of data to which
edge detection has been applied are medical x-ray image, satellite
imagery of the earth and radar contouring. The purpose of this paper
is the selection of an edge detection algorithm for use in a satellite
image system for the purpose of identifying land mass. The land mass
outline will be used for automatically registering line scan satellite
pictures of the earth by a correlation technique.\textsuperscript{2}

The historical methods of scene matching have been template
matching, that is, the direct correlation of an image pixel by pixel.
The obvious approach is the selection of stable patterns within a
scene. In a visual inspection of satellite meteorological images, the
obvious registration features are land areas surrounded by ocean. The
optical densities of these features are relatively stable and the scene
variations are generally effected uniformly by sun angle (a uniform
effect on the image) and clouds. The latter are characterized by
brightness and of temporal and spatial randomness.

Edge image detection was selected because of the economy of
data elements required to define the geographic edge features of land
mass versus the large data requirement to define textural quality of
land features. Because of the typically large volumes of data in-
volved, binary edge maps represent a significant compression in data
which may be manipulated in sequences rather than individual edge
points. A cost advantage is gained if the scene can be segmented
by appropriate classification i.e.: land and clouds; and from those
stable features be identified by a binary code. In an efficient
code to characterize the land, it is sufficient to identify the edge
at the land-sea boundary. This pixel can be identified by a binary bit in a word corresponding to a line scan. The edge would be identified by a binary '1' in the electronic scanned image and the location within the scan by digit position. A scan line is represented by a 1000 digit binary word and an edge location will be designated by a '1' in the corresponding location in the binary word. An application has been developed called a binary boundary map by Jayroe.

Advantages of using binary images to perform registration images are as follows:

1. They can represent the time independent shapes of ground features where as the tonal quality or grey value can change dramatically with times.
2. They compress the data used as input for correlation of temporal pairs of images.
   a. Minimize noise caused by temporal tonal changes which would be given equal weight in a grey level system.
   b. Minimize computer storage and processing time.
3. They should produce sharper correlation peaks with higher peak to background ratios than a grey level system.
4. They permit the derived correlation background values to have an approximate upper bound.
5. When slightly blurred or thickened, they can compensate for small changes in the shape or position of features.
over time, as well as small scale and rotation changes and still permit registration.

Edge filter technology has been evolved by heuristic and analytic approaches. Recent works considered for this application were by Jayroe, Andrus, and Campbell which is an application of the classical Roberts\(^5\) operation. Jayroe applies an edge operator to ERTS imagery and produces a compacted binary word to identify edge elements. A heuristic approach is taken by Nack\(^6\) and a set of edge operators are developed for multi-spectral imagery. A tabulation of operators used by Nack are listed in the following chapter. Nack claims a 100% success in performing registration using these algorithms. A linear system approach to edge detection is developed by Rosenfeld and Kak.\(^7\) This approach follows linear systems analysis techniques used by communication engineers and provides the theoretical basis for developing and evaluating the edge operator. The methodology requires a prior knowledge of the statistical properties of images. The latter approach was selected for application and the statistical data required was developed from sample image data.

Statistical properties of the imagery were derived from representative images analyzed on a GE 100 Image Analysis System which had the capabilities to select various representative portions of an image and measure their probability density functions. Having determined the statistical properties of the image, a decision criteria was established for the pixel gradient and its likelihood to be an edge.
CHAPTER II

EDGE DETECTION THEORY

Edge detection is a means to segment a picture by the identification of discontinuity in average grey level between adjacent picture elements indicating the edge of one region and the beginning of another. An idealized edge is the step edge where the level may be a step increase or decrease. The step may not be descriptive of nature. A satellite image of the edge of land may be a gradual transition in texture and intensity, i.e., vegetation, sand, surf, ocean, all leading to some function other than a step. A simple derivatives operator is $\frac{df}{dx}$ and $\frac{df}{dy}$ which gives the rate of change in x and y directions.

The linear combination

$$af = a_x \cos \theta + a_y \sin \theta$$

for digitized pictures, which will be of interest, can be defined

$$\Delta f(i,j) = \Delta f(i,j) \cos \theta + \Delta_y f(i,j) \sin \theta$$

where $\Delta x$, $\Delta y$ are the absolute difference between adjacent digitized pixel elements at $i,j$. The magnitude of the digital gradient is then
Various approximations have been made of this difference, e.g.:

\[ |\Delta_x f(i,j)| + |\Delta_y f(i,j)| \]  
(4)

or Max \(|\Delta_x f(i,j)|\) or \(|\Delta_y f(i,j)|\)  
(5)

or Max \(|f(i,j) - f(u,v)|\)  
(6)

where \(u, v\) is a neighbor of \(i,j\).

An edge derivation can be of second order (Laplacian) or higher order

\[ \frac{\partial^2 f}{\partial x'^2} = \sqrt{\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}} \]  
(7)

The classic Roberts operator (R) is taken over diagonal elements of a four pixel neighborhood.  

\[ R = \sqrt{A(I_d - I_a)^2 + B(I_b - I_c)^2} \]  
(8)

A, B are constants
\( I_a, b, c, d \) are pixel intensities, \( R \) can also be approximated by

\[
\text{Max}\left[ I_d - I_a \text{ or } I_b - I_c \right]
\]

(9)

Other heuristic edge detectors implemented by M. Nack are a nine pixel neighborhood weighting of the pixel values to form the gradient operator.

![Nine pixel neighborhood](image)

Fig. 2 Nine pixel neighborhood

The five characteristic edge operators used by Nack follow:

\[
\begin{align*}
R(1) &= \text{MAX} \left( \alpha D_{fd}, \beta D_{hb}, \gamma D_{ia}, \gamma D_{cg} \right) \\
R(2) &= \alpha D_{fd} + \beta D_{hb} + \gamma (D_{ia} + D_{cg}) \\
R(3) &= \alpha D_{fd}^2 + \beta D_{hb}^2 + \gamma (D_{ia}^2 + D_{cg}^2) \\
R(4) &= \alpha \left| (I_c + 2I_f + I_i) - (I_a + 2I_d + I_g) \right| + \\
&\quad \beta \left| (I_g + 2I_h + I_i) - (I_a + 2I_b + I_c) \right| \\
R(5) &= \alpha (D_{ed} + D_{ef}) + \beta (D_{eb} + D_{eh}) + \\
&\quad (D_{ea} + D_{ec} + D_{ei} + D_{eg})
\end{align*}
\]

(10) (11) (12) (13) (14)

where \( D_{ij} = |I_j - I_j| \) is the absolute value of the difference of the grey level pixel intensities \( I_i \) and \( I_j \).
The theoretical approach to deriving the edge algorithm is given by Rosenfeld and Kak\textsuperscript{10} using linear system analysis. The technique is dependent on a prior probability information which must be measured from the scene and assumed ergodic for the application. A best fit determination is used to place a plane through a nine pixel data set that is assumed to be the gradient at the center of the array. A minimum error detection criteria is computed from a sample image and used to determine the threshold criteria. The use of the best fit technique also builds in a spacial filter by averaging values over the dimensions of the rectangular pixel array. The best fit edge for a nine pixel neighborhood is

$$\Delta y = \sum_{i=1}^{i+1} (I_{1,j-1} - I_{1,j+1})$$

(15)

$$\Delta x = \sum_{j=1}^{j+1} (I_{i-1,j} - I_{i+1,j})$$

(16)

$\Delta x$ is horizontal edge component

$\Delta y$ is vertical edge component

$I$ is intensity of pixel

$i$ is row (scan line)

$j$ is column (scan line pixel)

The row and column operation form $\Delta x$, $\Delta y$ result in smoothing or filtering the data over the three element row and column. The
resulting of \( x, y \) is computed by combining these orthogonal elements by

\[
D = \sqrt{\Delta x^2 + \Delta y^2}
\]

and may be approximated by

\[
|\Delta x| + |\Delta y|
\]

or

\[
\text{Max } |\Delta x| \text{ or } |\Delta y|
\]

(17)

(18)

(19)

The edge will be detected when \( D \) exceeds a value \( (T_e) \). The error threshold will be determined from the edge density cumulative probability density function (Cpdf) of the corresponding image samples.

If the fraction \( \Theta_0 \) of the picture points are land, \( \Theta_b \) is ocean, and \( \Theta_e \) are border points, the overall error probability \( (P') \) when thresholding at \( t \) is

\[
P' = \Theta_o [1 - P'_o(t) + \Theta_e P'_e(t) + \Theta_b (1 - P'_b(t))]
\]

(20)

where \( P'(t) \) is the Cpdf of land and ocean gradients. The minimum error threshold \( T_e \) (min) is determined by differentiating equation 20 setting the result equal to zero and performing a numerical evaluation.

The subscript notation is "b" background or ocean, "o" object or land, and "e" boundary. After Rosenfeld and Kak 11 the minimum error threshold is

\[
\Theta_e P'_e(t) = \Theta_o P'_o(t) + \Theta_b P'_b(t)
\]

(21)

where \( p' \) are the probability density functions (pdf).
Because D is the geometric combination of orthogonal elements with a Gaussian pdf, the resulting pdf for the edge elements will be a Rayleigh distribution.

The form of the pdfs will be

\[ p'(z) = \frac{z}{\sigma^2} \exp \left[ \frac{-z^2}{2\sigma^2} \right] \]  

(22)

The value for the mode \( \sigma \) will be determined from measured sample data.
CHAPTER III

APPLICATION

Statistical data for determining the decision rules and error probability were measured using the GE Image 100 Processing System. The system permits convenient manipulation of density data, image storage, and processing techniques. The system has a built-in gradient function after Rosenfeld and Kak as shown in equation (21). The satellite image positive prints were input to the machine using a TV camera.

The most cloud-free pictures were used for land and ocean characteristics. Classification was made by the visual identification of modes (peaks) in the image intensity histograms and the correspondence with the original image was verified by displaying pixels associated with the particular mode. This verification is necessary because mode classification by histogram can be ambiguous, i.e.

The histogram for a picture of 50% black elements and 50% white elements are identical for salt-pepper patterns, checkerboard or other 1/2 black and 1/2 white patterns.

Characterization of image features for estimating the detection threshold were measured from a relatively cloud-free image. Table 1 lists the characterization of image features.
TABLE I
CHARACTERIZATION OF IMAGE FEATURES

<table>
<thead>
<tr>
<th>Feature</th>
<th>Probability Density p(z)</th>
<th>Mode Z</th>
<th>Variance</th>
<th>Percent Picture</th>
<th>Decision Rule</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>land</td>
<td>Gaussian</td>
<td>135.4</td>
<td>14.5</td>
<td>24.4</td>
<td>126&lt;T&lt;148</td>
<td>measured</td>
</tr>
<tr>
<td>ocean</td>
<td>Gaussian</td>
<td>101.6</td>
<td>11.0</td>
<td>41.2</td>
<td>90&lt;T&lt;111</td>
<td>measured</td>
</tr>
<tr>
<td>cloud and white grid</td>
<td>uniform</td>
<td>-</td>
<td>-</td>
<td>12.0</td>
<td>135&lt;T</td>
<td>measured</td>
</tr>
<tr>
<td>black grid</td>
<td>uniform</td>
<td>-</td>
<td>-</td>
<td>small</td>
<td>90&gt;T</td>
<td>estimate</td>
</tr>
<tr>
<td>edges</td>
<td>-</td>
<td>33.8</td>
<td>-</td>
<td>22.4</td>
<td>-</td>
<td>estimate</td>
</tr>
</tbody>
</table>

The histograms used for classification of ocean and land were used to determine the most probable difference threshold and its distribution at the edge. (Figs. 3a,3b)

Using the gradient operator of the system, histograms were developed over land and ocean area to provide the probability density function for the gradient in these areas respectively. (Figs. 4a,4b)

The Expected Value Of An Edge

The expected value \( \langle z_e \rangle \) of the gradient at the boundary is the difference of the expected value of the pdfs of the pixel intensities of the adjacent areas\(^{13} \) where z is the pixel intensity.
Fig. 3a Pixel intensity histograms, ocean sample
Fig. 3b  Pixel intensity histogram, land sample, West Florida
Fig. 4a Histogram, gradient intensity, ocean sample, Gulf of Mexico
Fig. 4b Gradient intensity histogram, land sample, West Florida
\[
\frac{z}{e} = |z_b - z_o|
\]  

Substituting values from Table 1 into equation (22) results in equation (24).

\[
p_e'(z) = \frac{z}{z_e^2} \exp \left[ -\frac{z^2}{2(z_e)^2} \right]
\]

The mode analysis of the histograms (pdfs) of the gradient from sample data of land and ocean is listed in Table 2. The following pdfs may be written using values from Table 2 and substituted into the form of a Rayleigh pdf.

\[
p_b' = \frac{z}{144} \exp \left[ -\frac{z^2}{288} \right]
\]

\[
p_o' = \frac{z}{146} \exp \left[ -\frac{z^2}{392} \right]
\]
TABLE 2
CHARACTERIZATION OF NINE PIXEL NEIGHBORHOOD GRADIENT IMAGE

<table>
<thead>
<tr>
<th>Feature</th>
<th>Probability Distribution</th>
<th>Mode</th>
<th>Decision Rule</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p'(z)$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gradient ocean</td>
<td>Rayleigh</td>
<td>12</td>
<td>$0&lt;T&lt;50$</td>
<td>measured</td>
</tr>
<tr>
<td>gradient land</td>
<td>Rayleigh</td>
<td>14</td>
<td>$0&lt;T&lt;48$</td>
<td>measured</td>
</tr>
<tr>
<td>gradient lake/land</td>
<td>Rayleigh</td>
<td>24</td>
<td>$2&lt;T&lt;127$</td>
<td>measured</td>
</tr>
<tr>
<td>whole picture</td>
<td>Rayleigh</td>
<td>12</td>
<td>$0&lt;T&lt;256$</td>
<td>measured with clouds</td>
</tr>
<tr>
<td>clouds</td>
<td>-</td>
<td>-</td>
<td>$135&lt;T&lt;256$</td>
<td>measured</td>
</tr>
</tbody>
</table>

The Minimum Error Threshold

The minimum error threshold is calculated using equation (21).

Where the image fractions of $\theta_o$, $\theta_b$, and $\theta_e$ are from Table 1 and substituting equations (24), (25), and (26) into equation (24)

$$\text{funct} \{\text{min}\} = \theta_o p_o'(z) + \theta_b p_b'(z) - \theta_e p_e'(z)$$

(27)

which is solved numerically and plotted in Figure 5. The minimum error threshold is $T_e = 34$.

Probability of Error Introduced by Clouds

The clouds can be classified by intensity and excluded from the
Fig. 5 Minimum error function vs. edge threshold
gradient algorithm. These pixels at intensity levels within the land-ocean classifications will remain and cause errors in the resulting gradient.

The cloud pixels whose intensities are below the threshold for exclusion are classified as land and ocean. They contribute noise and increase the spread of the Gaussian distribution and the effects are included in the calculation of the probability of the misclassification of edges.

**Probability of Misclassification**

The probability of misclassification is determined by the percentage pixels of the total gradient image that are above the edge classifier value $T_e$ that are not edges and those edge values less than $T_e$.

The misclassification is the sum of:

- $\{\text{Percent ocean gradient pixels}\} > T_e$
- $\{\text{Percent land gradient pixels}\} > T_e$
- $\{\text{Percent edge gradient pixels}\} < T_e$

The probability of misclassifying an edge element ($P'_e$) is

$$P'_e(z) = \int_{-\infty}^{T_e} p'_e(z) dz$$

and the probability that the land and ocean gradient exceed $T_e$

$$P'_o(z) = \int_{T_e}^{\infty} p'_o(z) dz$$
\[ P'_b = \int_{T_e}^{\infty} p'_b(z) \, dz \]  

(30)

\[ P' \text{ (misclas)} = \theta_p p'_p(z) + \theta_o p'_o(z) + \theta_e p'_e(z) \]  

(31)

After eliminating clouds, the weight factor \( \theta \) is corrected by \( K \)

\[ K = 1/(\theta_e + \theta_o + \theta_b) \]  

(32)

And using equation (22) in (28), (29) and (30)

\[ P'_e(z) = \int_{T_e}^{\infty} \frac{z}{\sigma_e^2} \exp \left[ -\frac{z^2}{2\sigma_e^2} \right] \, dz \]  

(33)

\[ P'_o(z) = \int_{T_o}^{\infty} \frac{z}{\sigma_o^2} \exp \left[ -\frac{z^2}{2\sigma_o^2} \right] \, dz \]  

(34)

And similarly for \( P'_b \). The value of the integrals are

\[ P'_e(T_e) = 1 - \exp \left[ -\frac{T_e}{2\sigma_e^2} \right] \]  

(35)

\[ P'_o(T_e) = \exp \left[ -\frac{T_e^2}{2\sigma_o^2} \right] \]  

(36)
\[ P_b'(T_e) = \exp \left( \frac{-T_e^2}{2\sigma_b^2} \right) \] (37)

Evaluating equation (31) using equations (35) through (37) at the minimum error threshold \( T_e \) equal to 34 and image factions \( \theta_e, \theta_o \)
and \( \theta_b \) from Table 1 where \( \sigma \) is the mode from Table 2, and correcting the result by factor \( K \) from equation (32), the probability of misclassification is 9 percent.

**The Results of Analysis of Sampled Data**

The classification of land, ocean and clouds was verified by displaying the pixels in the associated histogram modes and comparing the resulting image with the original. The expected difference between land-ocean modes was used to determine the Rayleigh pdf of the edge. The resulting pdfs were used to calculate the minimum error threshold and the probability of misclassification of edges. With the minimum error threshold \( T_e \) at 34, the probability of misclassification of the image for edges is 9 percent.
CHAPTER IV

SUMMARY

Edge detection is an economic method of classifying image data. The boundaries of similar data are identified and the classification information is encoded into a binary representation. The binary identification (edge, not edge) reduces the burden on the subsequent process. Correlation of the binary representation is significantly less complicated than the correlation of the full image densities. In addition, the correlation will be sharpened because of the binary form.

The heuristic approach of Nack has been successful. The significant factor within that algorithm is the ability to select the threshold of detection based on the edge density histogram. For on-line systems, this technique is demanding on memory requirements. Whole images must be stored and processed with each newly evaluated threshold.

The use of the linear system development of edge detection is recommended. There is a consistent systematic methodology developed in communications, decision, statistical, and information theory which can be called upon to exploit the edge process. This analysis can be expanded into discrete systems theory for analytical solution.
Starting with the primitive best fit gradient of Rosenfeld and Kak, spatial filter characteristics can be adjusted and higher order gradients become available. Prediction of system performance becomes possible through linear systems analysis and allows a rational approach to adjusting system parameters and operators.
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