Review of Automatic Contrail Detection Article

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Document Conventions

The use of the term "The article" represents the publication on Automatic Detection of Contrails, published in IEEE in 1998. See references [1]
Other papers are discussed in this review paper, which help discuss and build upon the previous research. They will be referenced as "papers" when they are discussed, if appropriate.

1.0 Introduction

This paper reviews and discusses the digital image processing topics presented in the article "Automatic Contrail Detection and Segmentation", which appeared in IEEE Transactions on Geosciences and Remote Sensing in September 1998. It is to be used in partial fulfillment of the requirements for completing the course numbered CSC751: Digital Image Processing.

2.0 Image Processing

In the atmosphere, one notices that airplanes seem to leave a trail behind them while soaring through the sky. These trails are called contrails, which is short for 'condensation trails'. They are formed by the inability of surrounding air to hold water vapor and, thus, clouds form. As the jet moves across the sky, a trail is created behind it and this forms a cloud. If the trail behind the jet is just water, why is it of interest to study?

As pointed out in this article, the emissions aren't only just water. The chemicals emitted may have various negative effects on the atmosphere, some of which are still being studied, and consequently affects the life that inhabits our planet. Other interested parties could include military planners, who might be interested in detecting recent jet flights, using the contrails as "tracers" for jets.

2.1 Difference Image

From the article, it is described that subtracting the data from AVHRR satellite data in channel 5 (11.8 um Infrared) from channel 4 (10.8 um Infrared) produces a better image for detecting contrails. The algorithm was first described by Englestad et al [8]. Why is this a better choice? When applying the differencing, it was detected that this combination produces an image with the contrails showing up as bright white, while the background is darker. This is optimal for ridge detection.

2.2 Contrast Stretching

The article briefly discusses contrast stretching as a method for enhancing the contrast of the image. The images that are taken by satellites of atmospheric aberrations have a visual smoothing that can result in false or missed contrail detection. The purpose of the contrast stretching transform is to increase the dynamic range of the gray levels in the image being processed. After differencing Channels 4 and 5, the resulting image appears "dark". One could include brightness as a modification, however this would result in all pixels increasing in value and thus the dark background would become "gray" in the output. Instead, the contrast stretch operation has the effect of increasing the ridge "height". Through experimentation, it was found that increasing the height 30-fold provided the best results over a wide range of images.

2.3 Histogram Equalization

The purpose of using Histogram Equalization is to increase the contrast in an image. Histogram equalization was mentioned in this article as an alternative approach to contrast stretching. However, as stated above, contrast stretching was used.

2.4 Smoothing

Smoothing is used to remove noise from images. In this article, it was presented that improved segmentation of contrails occurred after performing smoothing on the images. A center-weighted kernel was used, as they perform better than simple averaging filters.

3.0 Ridge Classification/Detection

Ridges, in the image processing sense, are lines of pixels that have larger pixel values than those on either side of the ridgeline. In order to detect ridges, we must provide and be able to enforce the definition for a ridge in an image. Every point along the ridge is a local maximum in at least one direction and inside a small neighborhood a ridge may be oriented in one of four directions: horizontally, vertically, or along the two diagonals [1]. Englestad [8, pp. 1396] diagrammed values in tables, Figure 3(a, b, c, d), for emphasis on how the actual pixel locations and values (in degrees centigrade) are involved for ridge detection.

A 6x6 neighborhood is used because the widths of contrails are usually only 3 pixels and can be detected with a 6x6 neighborhood. Using this mask, nine values are computed inside by summing groups of four adjacent pixels. Ridge location and direction are stored to be used for the Hough transform later.

One problem with ridge detection is that it detects ridges almost in every direction, due to noise and natural variations. In order to more accurately discover "true" ridges, a threshold value is assigned. To consider an area of the scene to be greater than another, a threshold had to be reached. The definition of a ridge uses the difference and is, thus, important to limit. It was experimentally determined that 0.2 degrees centigrade worked best.

Also, a score was used in the 6x6 neighborhood to "rate" the goodness of a pixel in relation to describing it as a possible ridge. If a neighbor has a temperature less than 0.8 degrees centigrade from the ridge in consideration, it is added to the score. If the final result is greater than 13, then it is classified as a ridge. This is done for the four orientations, and for every pixel in the image. If multiple orientations are discovered, the highest score wins. If the scores are equal, then the differences between neighbors are used and the greatest are chosen.

3.1 Hough Transform

The Hough Transform is used for extracting geometric shapes from images. One approach discussed and used in this article is the Hough Transform. The Hough Transform was used to discover lines (and consequently, a contrail) in the difference image. However, it was noted that more processing was needed because of several reasons. First, the contrails were sometimes dissipated; vary in width, or lines were directly beneath the Hough Transform. *How this is handled is discussed in section x. "Neural Networks"*

The Hough Transform is based on the idea of the slope-form equation for a line; y=mx + b. The *normal* form for a line is $\rho = x * \cos(\theta) + y * \sin(\theta)$. The normal equation for a line is preferred in the Hough transform because the slope of the slope-form equation approaches infinity as the line becomes vertical [2].

A discussion of the Hough transform hasn't been made in class, and the explanation of the algorithm falls outside of the discussion of this review paper. Consequently, I will not provide the intrinsic details of the algorithm.

In this article, several modifications were done to the Hough transform. For one, the Hough transform depends on finding lines usually by using an edge detection algorithm first. This was not used because the edge detection algorithms pick up all edges, including clouds, land-to-water boundaries, and other such terrestrial features. A ridge detector was used instead.

A characteristic property of a contrail is that it doesn't always follow a straight line through the entire scene. Englestad et. Al divided the image into 128x128-sized grids, which performed well to handle the derivation of a contrail path from a straight line.

Other problems, such as the parts of the contrail not being visible, or collinear with the Hough line segment exists.

3.2 Grayscale Thinning

Thinning is the process of decreasing the size of edges to form a connected line that is equidistant from its borders. In binary morphological operations, a person can use the hit-or-miss transformation as part of the algorithm to apply thinning. In grayscale thinning, however, a different scheme must be applied.

In order to perform grayscale thinning, we steal the binary thinning technique, but apply it to a smaller part of the image; in the case of [6], a 3x3 neighborhood size was used. Before we apply thinning, we must first convert the grayscale area into a binary representation, which is done using binary thresholding. Then, the center pixel of the 3x3 neighborhood is "thinned". If the value of the pixel is determined to be removed, the grayscale image pixel is updated with a grayscale intensity that is less than its previous value. What is this threshold for determining if the pixel can be removed and what is the value to replace it with? First, the threshold value must be selected to be the value of center pixel. If we choose a value greater than the center pixel, we end up thinning the pixel away. If the value is smaller, than we may end up having extra pixels that should have been thinned. The 2nd question is answered in [6], the neighborhood minimum is used to replace the current pixel's value. This grayscale thinning technique can be applied several times to derive the ridge.

4.0 Neural Networks

Neural Networks is a field of computer science that attempts to mimic the human neuron. The human neuron has an input, in the form of an electric pulse, and when enough pulses are received, a threshold is met. This threshold is the determining factor for the neuron, as to when it will generate an electric pulse, or "fire".

Although the article that I am attempting to review doesn't discuss the use of Neural Networks in contrail detection, the author has researched and written a published paper on the topic since then. It would not be complete without briefly covering the research that has been done since the first IEEE publication in 1998.

The paper [5] that discusses the use of Neural Networks for ridge detection is a continuation of this article. The author(s) use a 3-layer feed-forward back-propagation algorithm. As with any 3-layer network, it consists of an input layer, hidden layer, and output layer. The input layer represents pixel values, the hidden layer acts as a layer between the input and output layer, and the output layer usually provides the classification results of the input, in this case the ridge magnitude, or strength, of a pixel.

In the paper [5], the input layer's numbers of nodes vary with the neighborhood shape and size. In figure 4.1, the neighbor shapes that were tested are displayed. The plots are representative of actual sizes that were used. In most cases the sizes were greater.

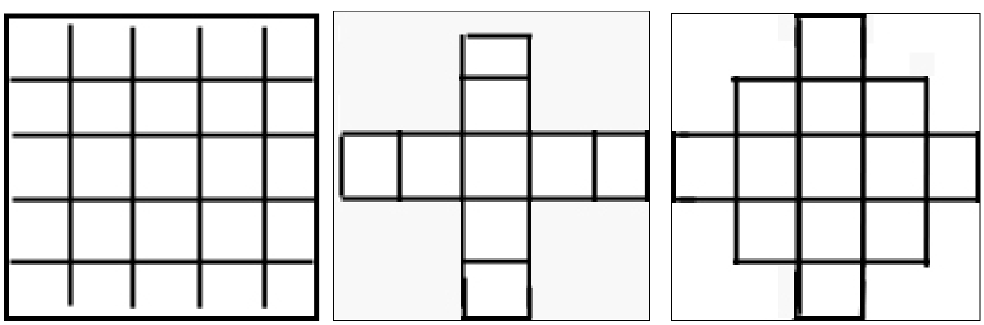

Figure 4.1: Input patterns/pixels for the back-propagation network. (a) Represents inputs for a square pattern of 5x5 pixels (25 inputs); (b) represents a plus-shaped input pattern (5x5, 9 inputs); (c) represents a hybrid pattern of 3x3 square pattern and 5x5 plus-shaped pattern.

If the size of ridges were larger than the masks used, then grayscale thinning was applied to fit the ridges to the masks. Alternatively, the plus-shaped pattern can be used, as it requires less input points to cover a larger area of pixels. Incidentally, the hybrid input patterns gave the best results.

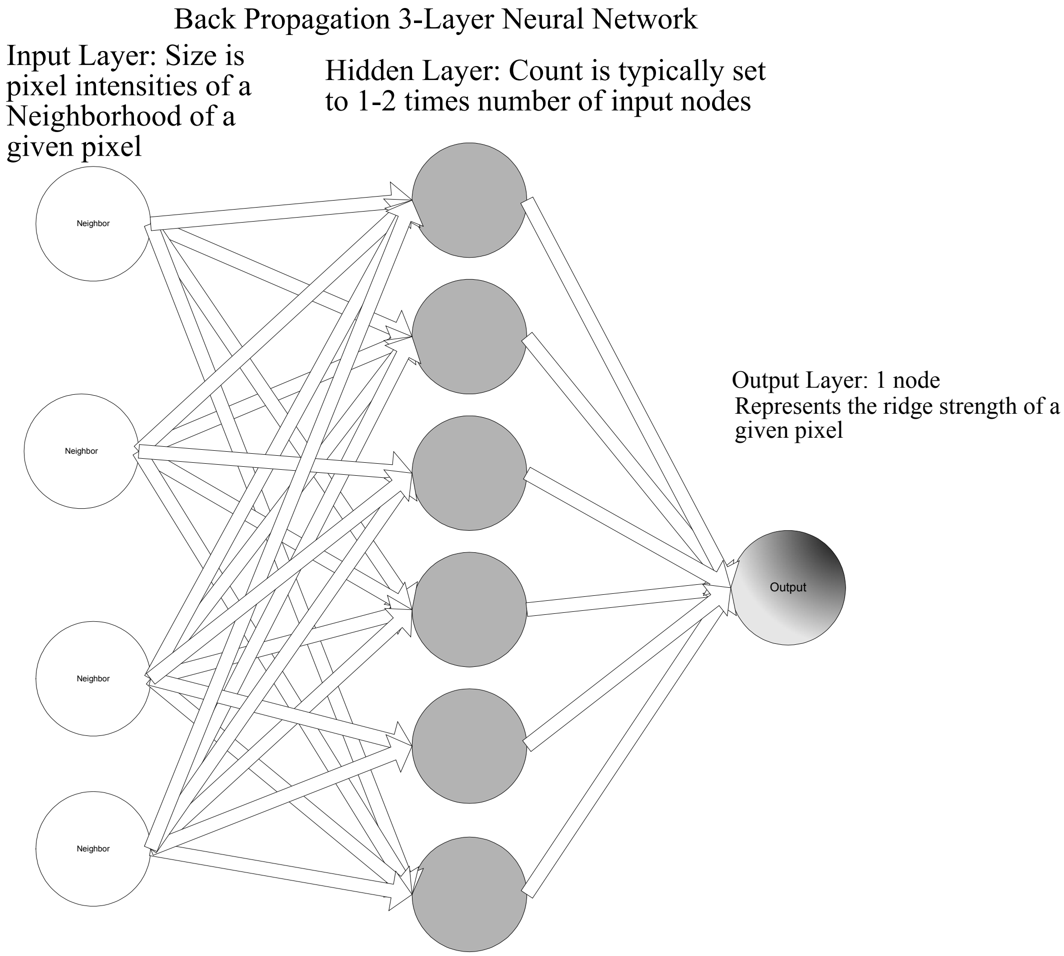

Figure 4.2: Demonstrating a 3-layer network, much like the one used in [5]. Note: Input layer and hidden layer have been scaled to save time. An actual pixel neighborhood would most likely include more neighbors. It is important to note that the term “neighborhood”, in this paper, represents the pixel and its surrounding pixels.

5.0 Summary of Method

1) Acquire Satellite images, specifically channels 4 and 5
    a. Perform Pre-Processing Steps: e.g., Image Registration.
2) Perform differencing of channel 5 from 4.
    a. Perform “rescaling” on data from temperatures to intensity levels.
3) Apply linear contrast stretching.
4) Apply Smoothing
5) Apply Ridge Finding Algorithm (Note: using temperature values)
    a. Store direction and location for (6).
6) Apply Hough Transform algorithm
7) Locate contrails using the accumulator arrays from (6)

6.0 Conclusion and Thoughts

Ridge detection is a very important and powerful technique that can be used in more than one arena. There has been much study into detecting contrails and the research continues as the need arises.

I have read this article, along with some of its references and the articles that precede it and have found the material very involved. Not only must one perform the basic image processing transforms, but also “tweak” each one to perform to desired standards. For most I.P. operations, this is expected. As Dr. John Weiss has pointed out in lectures; “Image Processing is generally an ad hoc field.”

If I had any suggestions, they would be primarily for future research areas. For example, there is literature on using Markov Random Fields for unsupervised classification of regions in satellite images. Could this somehow be used, in conjunction with already proven methods, to discover contrails based on probabilistic reasoning? Basically, there are many techniques to research and not enough time to do it. And, the results from the current work are sufficient and ideas can be readily used in other signal processing/image processing applications.

Appendix A: Definitions

Albedo: Albedo is the fraction of solar energy (shortwave radiation) reflected from the Earth back into space.

Anthropogenic: Scientists use this word to distinguish changes to the Earth’s environment that are caused by humans.

Collinear: Two points are *trivially* collinear if they ‘live’ on the same line. Three points, x1, x2, x3 are collinear if they lie on a straight line.

Contrails: Condensation trails. These are typically created by an aircraft’s exhaust.

Earth Radiation Budget: This is the concept of the Earth maintaining a balance between the amount of incoming radiation (space-to-earth) and the outgoing radiation (Earth-to-Space). This radiation involves shortwave (solar) radiation, longwave radiation, and albedo. Clouds, dust, pollution and greenhouse gases (and contrails!) influence the transport of energy in the atmosphere in complex ways.

Erosion: The value of the output pixel is the *minimum* value of all the pixels in the input pixel's neighborhood. In a binary image, if any of the pixels is set to 0, the output pixel is set to 0.

Hough Transform: A line (and geometric shape) detection algorithm which perform global processing to determine subsets of lines in an image. It has a speedup over basic line detection algorithms in that it uses accumulator cells to divide the parameter space.

Nadir: the lowest or deepest point.

Ridge: A ridge is a connected linear structure that is very long relative to its width, with a skeleton along which the pixels intensities change slowly.

Segmentation: Segmentation is the process of splitting an image into regions.

Threshold Superposition Principle: The idea that an grayscale-image can be broken down into subparts by thresholding the image on every intensity level from 0 to max+1 (256, in 8-bit grayscale images).

Appendix B: Figures

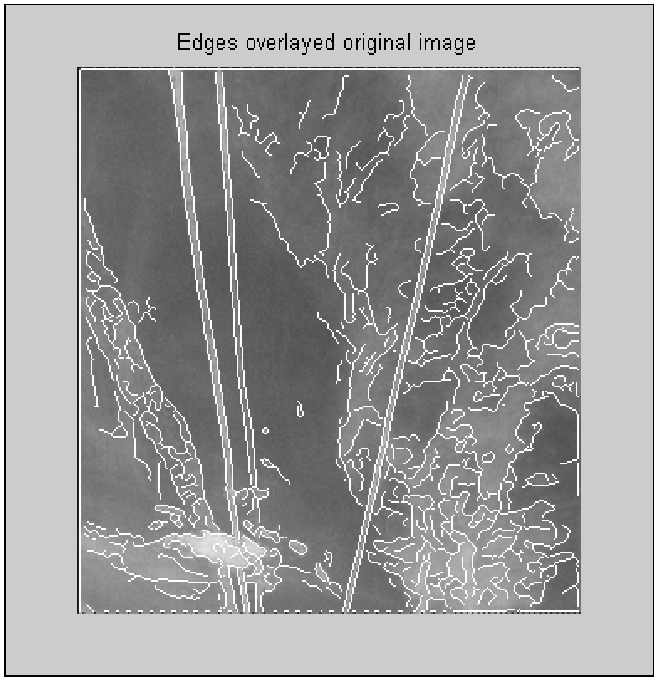

Figure B.1: *Original image with edges that were detected overlayed. Note that the thin contrails in this image are easily visible to a human. This picture was taken from the ground. The point of providing this figure is to give more emphasis and thought to how an engineer would write algorithms to automatically detect contrails.*

Demonstration of Erosion and Binary Thinning in Matlab

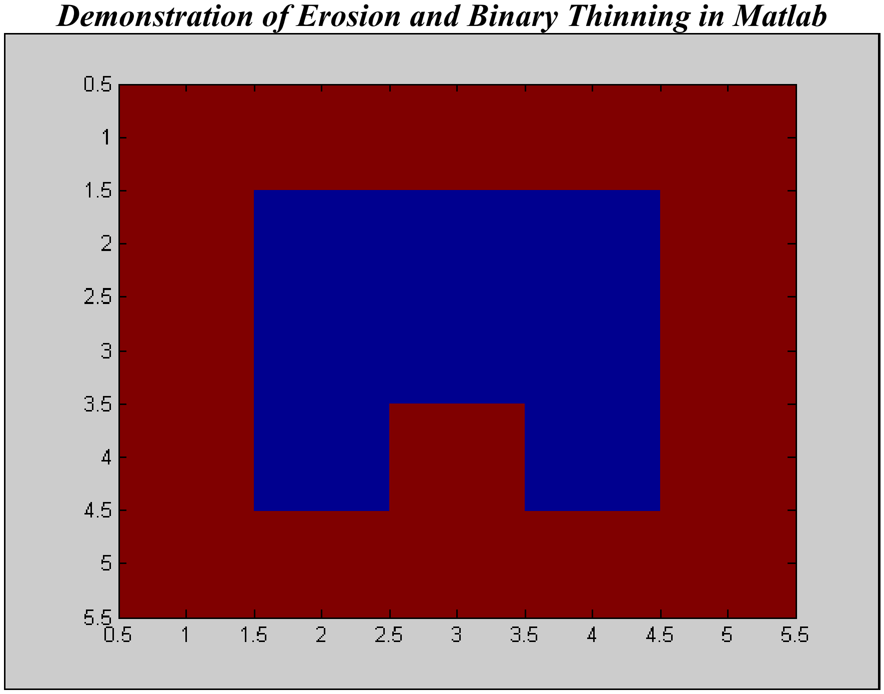

Figure B.2: *Original 5x5 image. Red squares represent 1s, blue's represent 0. Note: image is a square, with a "notch" near the bottom. We would like to preserve this shape.*

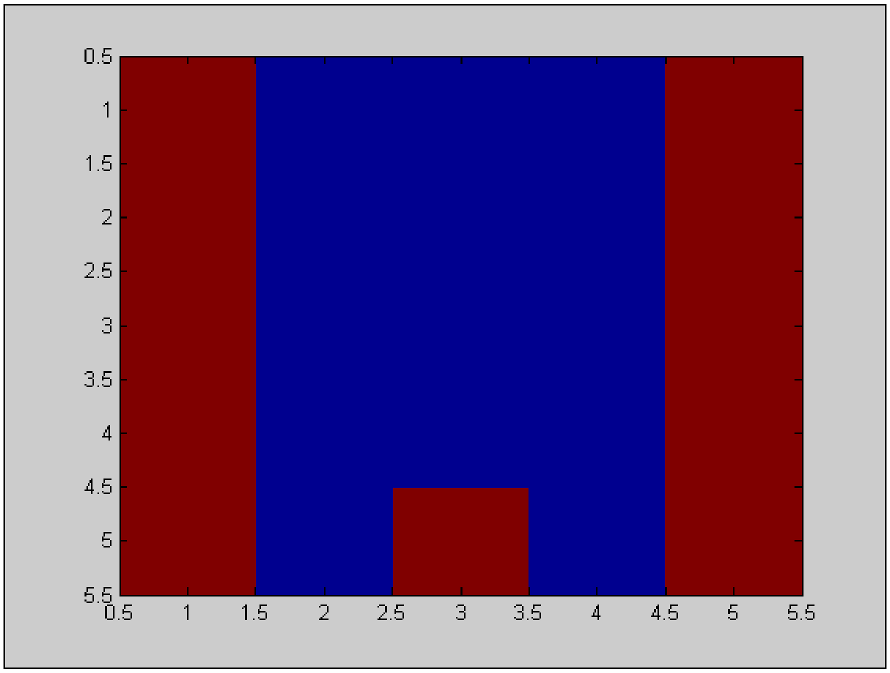

Figure B.3: *"Eroded" 5x5 image. Red squares represent 1s, blue's represent 0. Note, the component doesn't stay connected (by choice of mask). Thinning, however, tries to keep the connected components connected, while eroding the structure.*

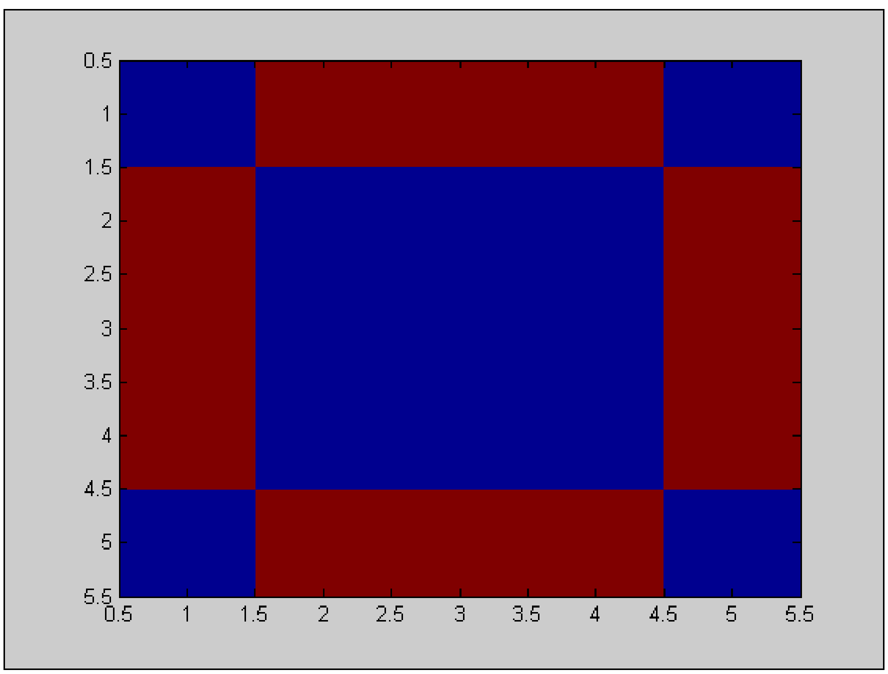

Figure B.4: *"Thinned" 5x5 image from figure 2. Red squares represent 1, blue's represent 0. Note that the components stay (at the very least, diagonally) "connected".*

References

[1] Weiss, John M., Christopher, Sundar A., Welch, Ronald M., *"Automatic Contrail Detection and Segmentation"*, http://www.atmos.uah.edu/~sundar/papers/IEEE%20GeoRem%201998.pdf

[2] Woods, Richard, Gonzalez, Rafael, "*Digital Image Processing*", Second Edition, Prentice Hall, 2002

[3] "NASAs Mission to Planet Earth and the Earth's Radiation Budget", http://asd-www.larc.nasa.gov/edu/

[4] Meinert, Dieter, "*Neural networks to detect contrails in satellite images*", http://www.aip.de/~dieter/Summary_for_Schumann/node2.html#SECTION00020000000000000000

[5] Weiss, John M., Kishore, Rishi, "Ridge Detection Using Artificial Neural Networks", 87th Annual Meeting of the South Dakota Academy of Science, Apr 2002.

[6] Weiss, John M., "Grayscale Thinning", Publication Unknown, Publication Date Unknown.

[7] Levesque, Vincent, "*Measurement of Skin Deformation Using Fingerprint Feature Tracking*", http://www.cim.mcgill.ca/~vleves/homepage/master/, November 2002

[8] M. Englestad et al., *"Automated Detection of Jet Contrails Using the AVHRR Split Window"*, Intl. Journal of Remote Sensing, 1992, Volume 13, Number 8, 1391-1412