

Recognition of Spectral Patterns

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Presentation Overview

- Introduction to pattern recognition
- Automatic Target Recognition (ATR)
- Maximum Average Correlation Height (MACH Filters) Simulation
 - Filter Selection Method
 - Application of the Correlation Filter Coefficients
 - Peak-to-Sidelobe Ratio (PSR) Post-processing
- ATR/Optical Correlator Data Analysis
- Future extension
- Conclusion

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Pattern Recognition

- Applicable to disparate fields of inquiry: handwriting and gesture recognition; DNA sequence identification, geological analysis, etc.
- Note the biological (neurological) roots in developing pattern recognition systems
- Chapter 10 in our text is “Pattern Formation”

Pattern Recognition

- “Pattern recognition – the act of taking in raw data and making an action based on the category of the pattern - has been crucial for our survival , and we have evolved highly sophisticated neural and cognitive systems for such tasks.”

Richard O. Duda

Automatic Target Recognition

- Recognition of spectral patterns through the utilization of an optical correlator is an integral category of the mathematical domain of pattern recognition - and more generally - pattern classification.
- Correlation filters have been utilized with much success in automatic target recognition (ATR) applications.
- Domain of this research specifically relates to the utilization of optical correlation filters on ground-based tactical targets.
- Evaluation of the MACH (Maximum Average Correlation Height) filter for ATR and aimpoint analysis against these high-value, defense targets with background clutter using an infrared seeker.

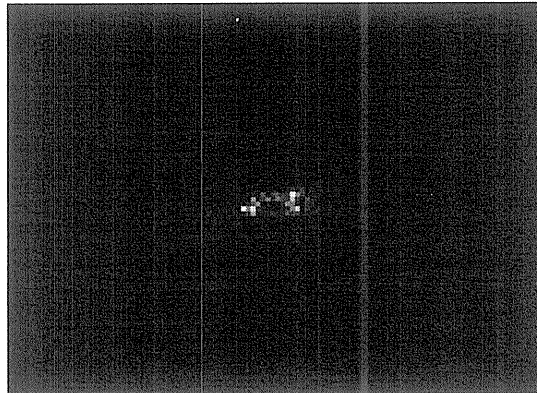
Correlation Filter Explanation

- Correlation filters may be considered as a signal detection approach to ATR and may be considered as a general-purpose matching engine.
- Correlation filters are designed (with respect to target class, aspect angle, etc.) to provide the optimal (i.e., the most invariant response) of the filter with respect to the target image.
- As we will see, the basics of this field are founded in considerable rigor in applied mathematics.

Correlation Filters: Algorithm Rationale

- Results in sharp correlation peaks for targets of interest, as well as high discrimination against unwanted objects; specifically clutter, decoys (noise)
- Have excellent robustness to noise in the input scene as well as a high tolerance to distortions.
- Strike a balance between robustness (wrt noise) and simplicity in order to be realizable in the real world

Example Tank Imagery



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Real-time Performance Considerations

- Closing rate of a missile intercept is (> 4 km/sec)
- Abbreviated time window to perform ATR processing
- Factor processing speed requirements and resulting throughput requirements

Current Research

Duda, Richard et al, Pattern Classification, John Wiley and Sons

Islam, M.F., et al “Pattern Recognition in Hyperspectral Imagery Using Dimensional Maximum Average Correlation Height Filter” *Proc. of SPIE Vol. 6566*

Mahalanobis, A. “Improving the False Alarm Capabilities of Composite Correlation Filters” *Proc. of SPIE Vol. 3718*

Mahalanobis, A. *et al* “Utilization of Optical Correlator for Automatic Target Recognition” *Proc. of SPIE Vol. 4043*

Mahalanobis, A. “Processing of Sensor Data Using Correlation Filters” *Proc. of SPIE Vol. 3466*

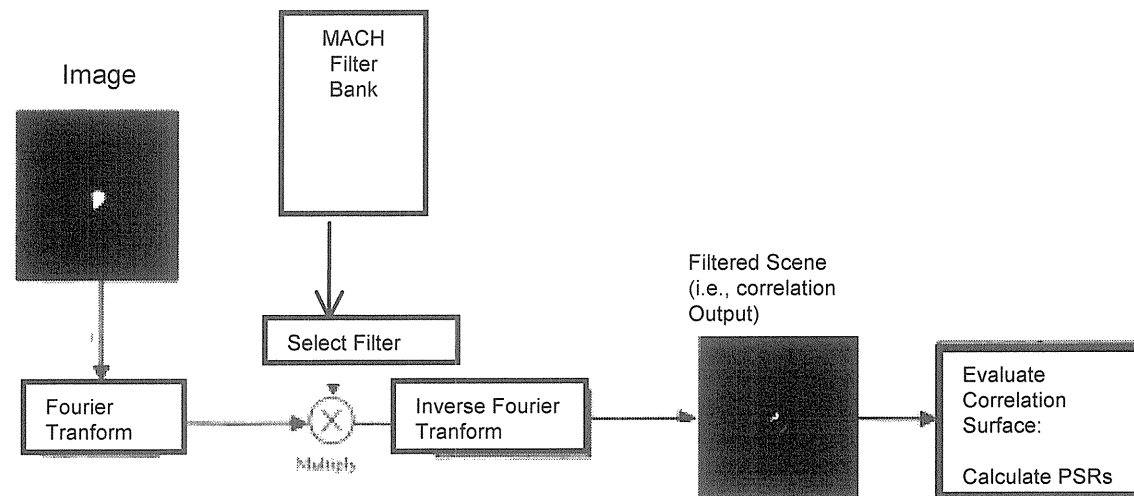
Pitas, I, Digital Image Processing Algorithms and Applications, John Wiley and Sons,

Walls, Bradley *et al* “ Performance of the MACH Filter Algorithm” *Proc. of SPIE Vol. 3718*

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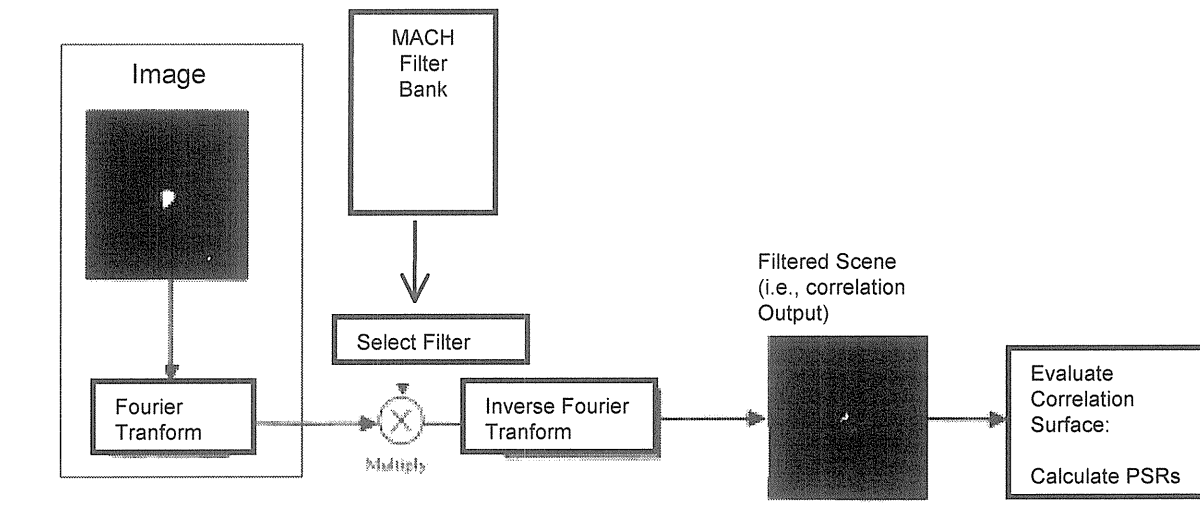


ATR MACH Algorithm Overview



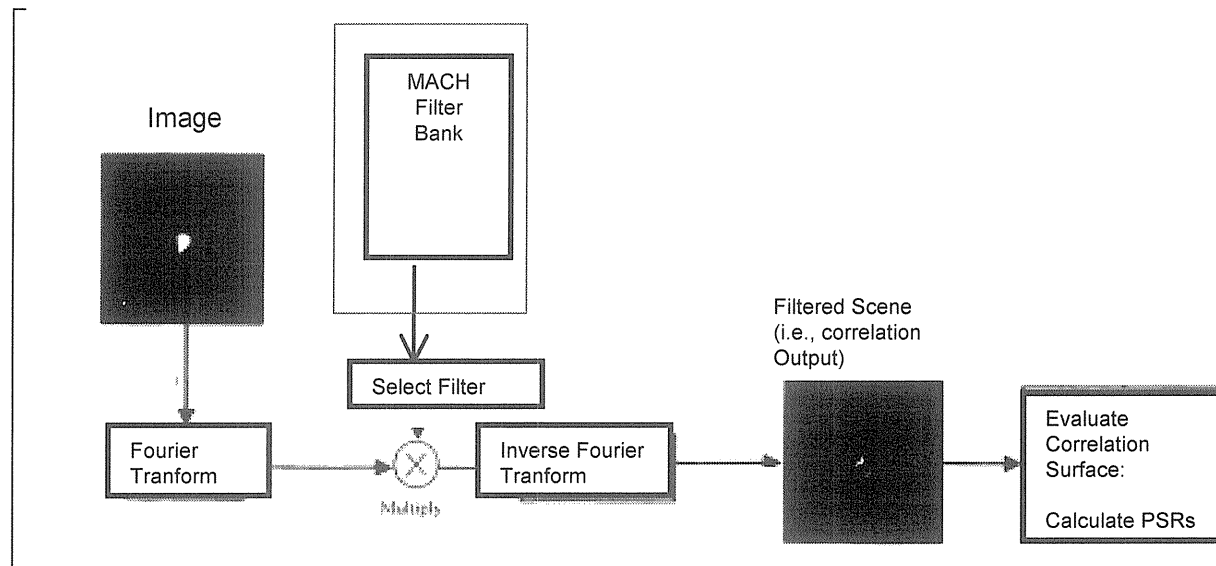
- Input IR scene image is cross-correlated with a carefully designed correlation template;
- Specifically, cross-correlation means the two-dimensional spatial correlation for the large matrices. Ultimately, the FFT is utilized to transform this spatial correlation into a Fourier-domain element-by-element multiplication.
- Correlation filters are used to detect and locate targets in observed scenes.
- Evaluate the correlation surfaces created with an input image and a bank of filters
- Resulting output is searched for large peaks.
- Designed to maximize the amplitude (height) of the mean correlation peak with respect to expected distortions.

ATR MACH Process



- Each image is correlated with the relevant filters in the filter bank.
- As shown, each image is FFT'ed one time and then it is correlated against all the aspect filters within the relevant filter bank.
- Peaks in the resulting correlation surfaces will have peaks that show both the locations as well as the intensities of the best "matches" with regard to the corresponding filters.

ATR MACH Process

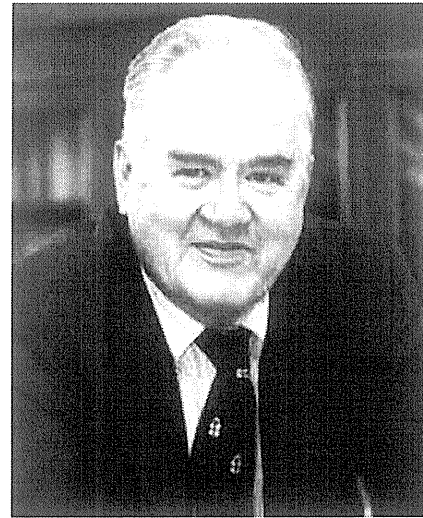


- The filter bank is created for the designated target at various aspect angles
- As such, it is designed to maximize the amplitude (height) of the mean correlation peak with respect to expected distortions.
- Prior to the first use of the filter banks, each of the MACH filters is transformed from its initial spatial format to a Fourier domain format. This method occurs prior to the initial use of the filter bank in the subsequent correlation.
- As such, this procedure helps to minimize the system throughput requirements.

Historical Context: Key Mathematicians



Jean Baptiste Fourier *
Ecole Polytechnique
French mathematician and physicist

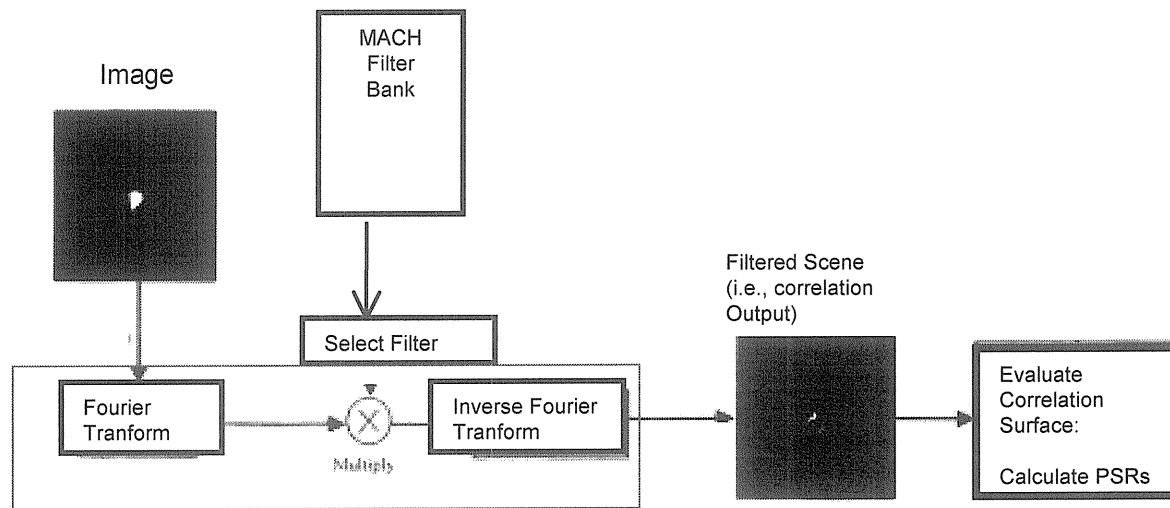


John Tukey
Princeton University
Fast Fourier Transform - Efficient
algorithm to compute the
discrete Fourier transform and its inverse

*Fourier is also credited with the discovery in 1824 that gases in the atmosphere might increase the surface temperature of the Earth, what is now called the greenhouse effect.

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ATR MACH Process



- Since this process can be extremely throughput intensive for image matrices, specifically the two-dimensional spatial correlation.
- Consequently, the “Fast” correlation (i.e., FFT) is employed to transform a spatial correlation into a Fourier-domain, element-by-element multiplication.

Application of the Correlation Filter Coefficients

$$g_{k,c,\theta} = \hat{I}_k(u, v) \otimes h_{c,\theta}$$

where:

$g_{k,c,\theta}$ variable is the correlation image

$\hat{I}_k(u, v)$ variable is the k^{th} image,

\otimes method is the two-dimensional spatial correlation;

$h_{c,\theta}$ variable is the filter coefficients in the spatial domain

Correlation Surface Process

$$g_{k,c,\theta} = \left(\left(\mathfrak{F}_{2D}^{-1} \left(\mathfrak{F}_{2D} \left(\hat{I}_k(u,v) \right) \hat{\bullet} H^*_{c,\theta} \right) \right) \right)$$

Where:

c and θ are the variables for the target class and aspect bin.

$\hat{\bullet}$ symbolically denotes the method for element-by-element multiplication.

$\hat{I}_k(u,v)$ is the variable for the k^{th} pre-processed image, and H^* is the variable for the selected filter.

As shown in this equation, the FFT (\mathfrak{F}_{2D}) of the image and the appropriate filter are combined via an element-by-element multiplication, and inverse FFT (\mathfrak{F}_{2D}^{-1}) transformed.

MatLab Realization

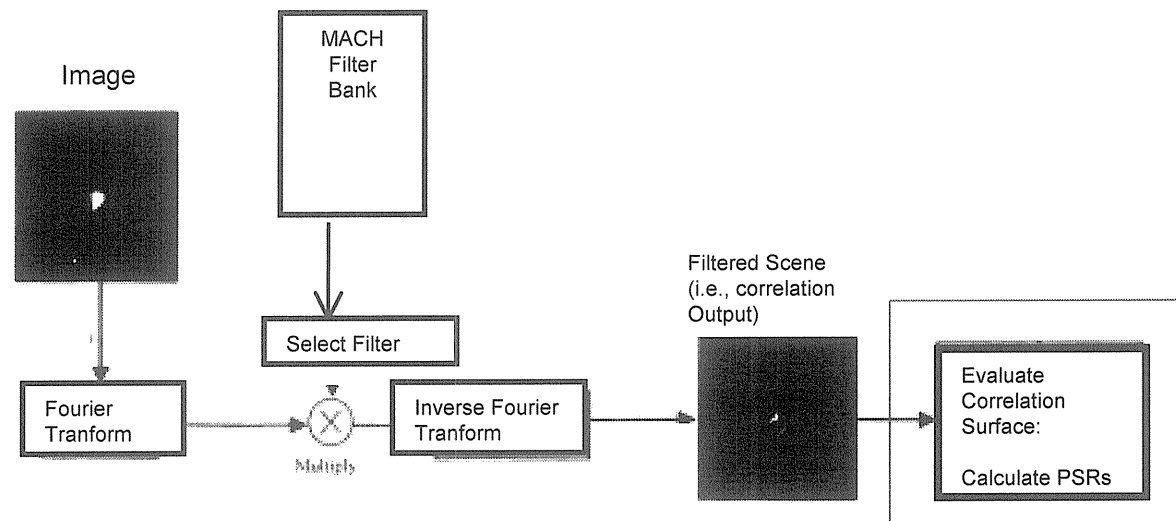
- Image Processing Toolbox:

$Y = \text{fft2}(X)$

Description

$Y = \text{fft2}(X)$ returns the two-dimensional discrete Fourier transform (DFT) of X , computed with a fast Fourier transform (FFT) algorithm. The result Y is the same size as X .

ATR MACH Process



- This post-processing method is applied to the correlation surface in order to evaluate the relative strengths of the correlation peaks.
- This method computes the Peak-to-Sidelobe Ratio (PSR) for each point on the correlation surface.
- As each correlation surface is produced, the post-processing function transforms the correlation surface into a PSR surface.
- The PSR surface is then searched for the maximum value.

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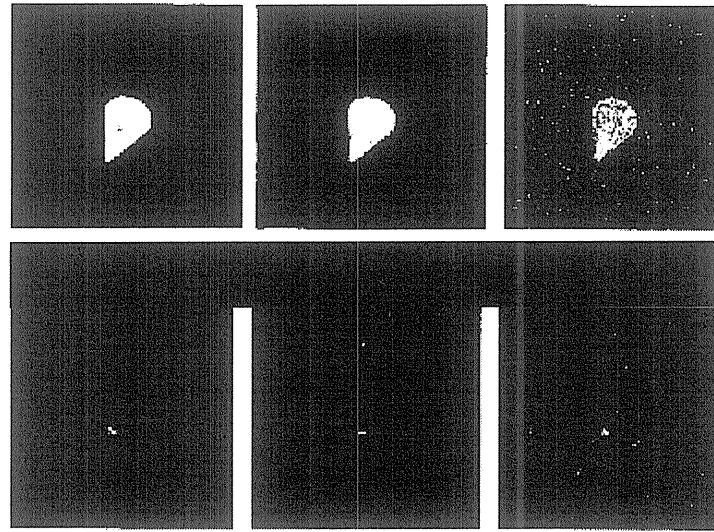
Peak-to-Sidelobe Ratio (PSR) Computation

$$PSR = \frac{peak - \mu}{\sigma}$$

Where:

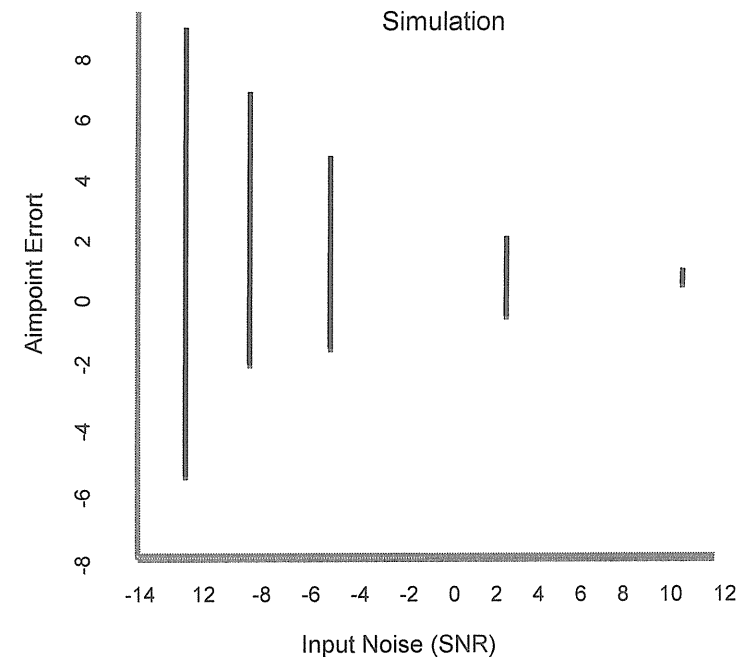
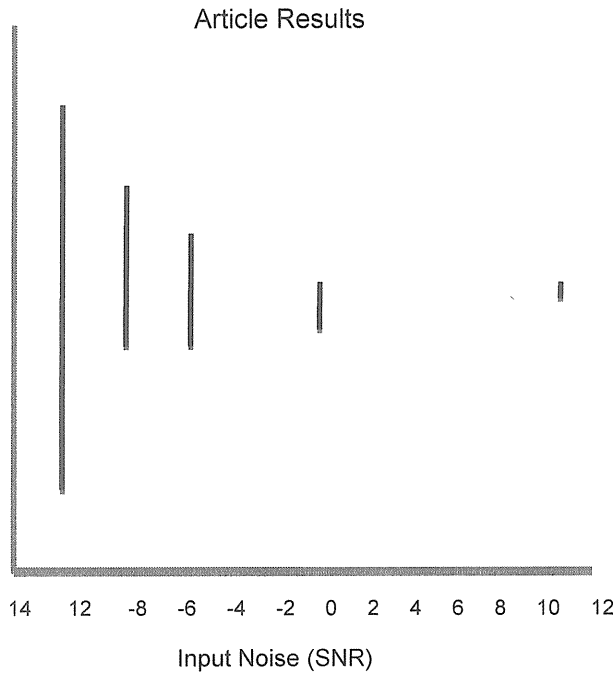
- $peak$ is a peak response in the correlation surface;
- μ the mean response local to the peak;
- σ is the standard deviation local to the peak.
- As shown mathematically in the equation, the MACH filter minimizes the mean and variance of the response while maximizing the peak; this, in turn, maximizes the PSR.

IMAGES AND CORRELATION SURFACE INTENSITIES



- The first image set depicts the results of a MACH filter on an image with very little system noise. Note that the resulting correlation surface is very clean and the peak PSR value is quite clear.
- Subsequently, as shown in the figure on the right (above), the same input image then had a few random noise pixels added. As shown in the figure on the right (below), the correlation surface now has considerable more clutter as a result of the noise.
- However, the target response continues to be evident in the context of that of the surrounding noise peaks. Notwithstanding the increased processing for the PSR calculation than simple peak detection, the data suggests that it better measures the response of the MACH filter

Comparison of Results: Error Analysis



These graphs show the results of how the target aimpoint error is affected by the addition of random noise. As shown, the aimpoint error is quite good through a SNR of -6 dB. The results of published paper are shown on the left. The simulation reproduction is shown on the right. Synthetic imagery (pristine and with random noise) was utilized to ascertain the robustness of the MACH performance. As shown, with regard to the comparison of the results, the target aimpoint error was similarly affected by the introduction of random noise. Specifically, consistent with the original model, the aimpoint error is quite good through a -6 SNR. However, since the introduction of the noise was random, the exact errors are not reproduced; however, the fidelity of the data trend is faithfully maintained.

Future Extension

- A bipolar threshold condition is explored in the algorithm to permit the option to detect targets that are colder (i.e., minimum value), in which case, the absolute value of the minimum value is computed.

Conclusion

- The MACH filter algorithm has great potential with regard to research applications in science and industry.
- The performance of the MACH demonstrates robustness; the military implications of this research are quite obvious with regard to automatic target recognition.
- However, much refinement is needed to render the algorithm useful under tactical battlefield situations.
- In another domain, the medical industry, such as the automatic assessment of mammograms may be another useful application of the MACH filter.

Questions?