Generalized Complex 2D Matched Filtering for Local Regular Line-Like Feature Detection

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Contribution

Following the theory of *Complex 2D Matched Filtering* (**CMF**), we introduce the *Generalized Complex Matched Filtering* (**GCMF**) approach. **GCMF** contains a bank of angle invariant filters, where each filter is denoted by the order. **GCMF** can be used to detect a broader range of image details: edges, lines, line intersections and corners; and the **GCMF** provides additional information about the detected features - the rotation angle. Each kernel from the **GCMF** bank is analyzed in polar coordinates and the specifics of feature detection are explained. A method of generating **GCMF** normalized kernels of arbitrary order is proposed.

Introduction

Building pattern recognition systems it is usually necessary to detect different image details, like edges, lines, corners, blobs, etc. A bank of specific filters, matching each individual detail for this purpose can be used. As the details usually are oriented in different directions and have different scales, the image processing leads to many convolution operations. This approach is known as *Matched Filtering* (**MF**) [1]. While being very effective at extracting an object from noise, it can be very slow for 2D signals, because of the need to rotate the filter kernel. In our previous work, [2] we have introduced an angle invariant method – **CMF** which is based on the **MF** approach. **CMF** not only extracts lines, but also obtains their angular orientation. **CMF** uses only one complex kernel instead of many rotated masks; therefore, it is more computationally efficient than the **MF** approach.

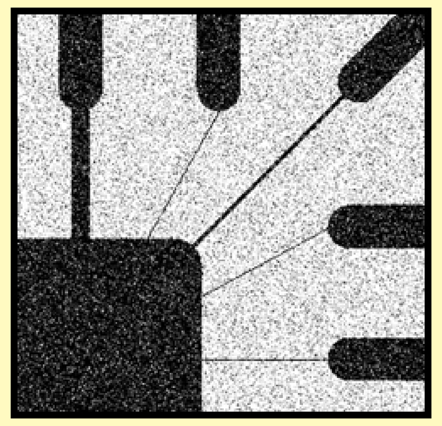
References

[1] S. Chaudhuri, S. Chatterjee, N. Katz, M. Nelson, and M. Goldbaum. Detection of blood vessels in retinal images using two-dimensional matched filters. In *IEEE Transactions on Medical Imaging, Vol.8, Issue:3*, pages 263–269. IEEE, 1989.

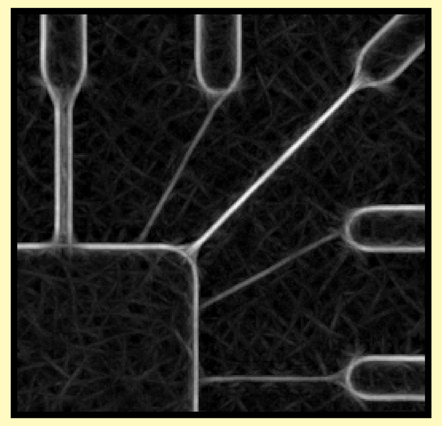
[2] M. Greitans, M. Pudzs, and R. Fuksis. Object analysis in images using complex 2d matched filters. In *EUROCON 2009: Proceedings of IEEE Region 8 conference*, pages 1392–1397. IEEE, 2009.

[3] M. Greitans, M. Pudzs, and R. Fuksis. Palm vein biometrics based on infrared imaging and complex matched filtering. In *MM&Sec '10: Proceedings of the 12th ACM workshop on Multimedia and security*, pages 101–106, New York, NY, USA, 2010. ACM.

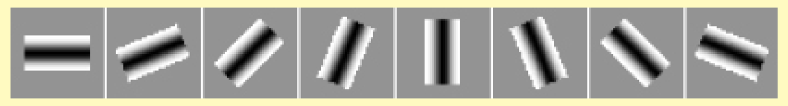
Matched Filtering



a) Test image $f(x,y)$



b) Filtered with MF $g(x,y)$

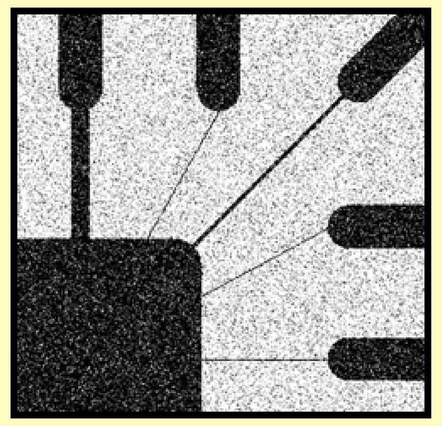


Eight rotated MF masks

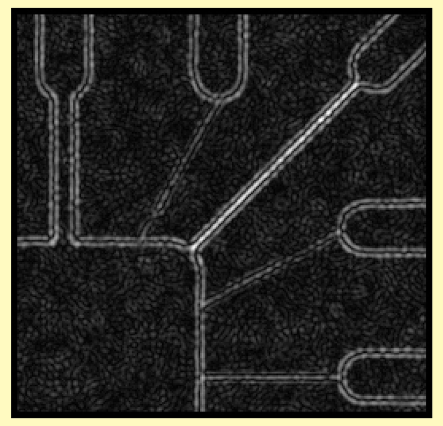
$$g(x_0,y_0) = max \sum_x \sum_y f(x,y) \cdot M_\varphi(x-x_0, y-y_0) \quad (1)$$

MF effectively maximizes signal to noise ratio and the filter masks can be chosen arbitrary, however, there are significant drawbacks, such as slow performance because of the need to rotate the filtering masks and the obtained result that is in scalar form; therefore, no additional information about the object is obtained.

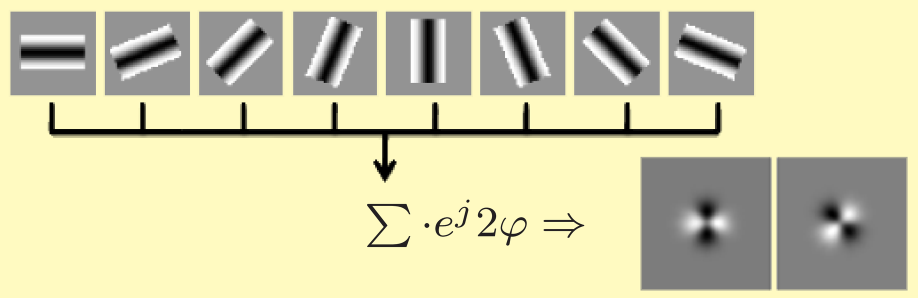
Complex 2D Matched Filtering



a) Test image $f(x,y)$



b) Filtered with CMF $w(x,y)$



$\sum \cdot e^{j2\varphi} \Rightarrow$

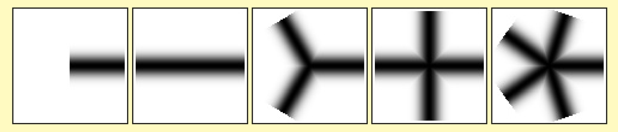
Combining MF masks to obtain CMF complex mask

$$\underline{M}(x,y) = \sum_l e^{j2\varphi_l} \cdot M_{\varphi_l}(x,y) \quad (2)$$

$$w(x_0,y_0) = \sum_x \sum_y f(x,y) \cdot \underline{M}(x-x_0, y-y_0) \quad (3)$$

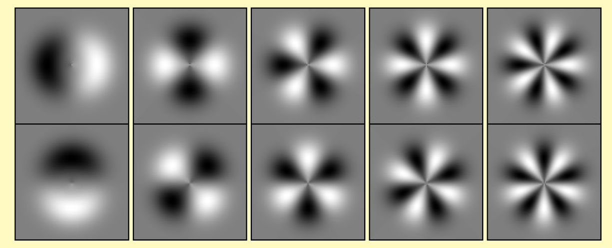
CMF mask is equal to the **CMF**$_2$ filter kernel.

GCMF



MF masks (M_K) of first five orders (K=1,2,...,5)

$$\underline{M}_K(x,y) = \sum_{n=0}^{N-1} e^{jK\varphi_{K,n}} M_K(x,y;\varphi_{K,n}) \quad (4)$$



First five GCMF kernels, top - Re part, bottom - Im part

First five orders of **MF** masks are transformed in to **GCMF** kernels by applying equation (4).

$$\underline{M}_K(\rho,\theta) = e^{jK\theta} \cdot \int_0^{2\pi} M_K(\rho,\tau) e^{-jK\tau} d\tau = e^{jK\theta} \cdot \underline{r}(\rho) \quad (5)$$

Equation (5) defines **GCMF** kernel in polar coordinates. $\underline{r}(\rho)$ is radial component.

Neighborhood Function

GCMF process formally can be described as:

$$\vec{c}_K(x_0,y_0) = \sum_x \sum_y f(x,y) \underline{M}_K(x-x_0, y-y_0) dx dy \quad (6)$$

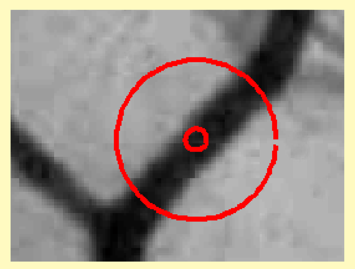
Polar neighborhood function around (x_0,y_0):

$$\underline{R}(\theta) = \int_0^P f(\rho,\theta) \cdot \underline{r}(\rho) \rho d\rho \quad (7)$$

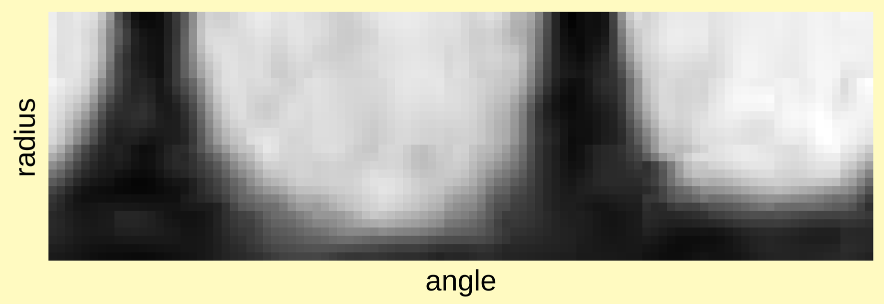
CMF$_K$ calculates K-th coefficient of the neighborhood function's complex Fourier series:

$$\vec{c}_K(x_0,y_0) = \left[\int_0^{2\pi} \underline{R}(\theta)^* \cdot e^{-jK\cdot\theta} d\theta \right]^* \quad (8)$$

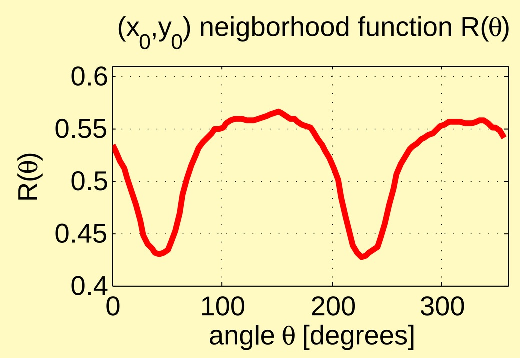
Figures below demonstrate how a line is detected with neighborhood function's second harmonic.



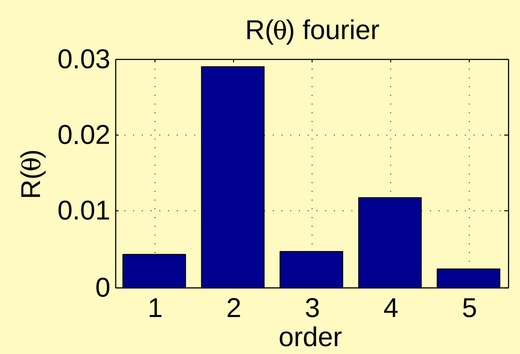
a) Test image



b) Test image in polar coordinates



c) Polar neigborhood function



d) Fourier series

Acknowledgements

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IEGULDĪJUMS TAVĀ NĀKOTNĒ
EIROPAS SAVIENĪBA

Conclusions

We introduce the theory of generalized complex 2D matched filtering method for the regular line-like feature, that include edges, lines, line crossings and corners, extraction from images. A mathematical form for filter kernel generation and it's relationship with matched filtering is explained. If an appropriate radial component $\underline{r}(\rho)$ is chosen, **GCMF** detects corresponding details of different orientations and scales, using only one convolution operation with the complex mask.

Main advantage of **GCMF** approach is an ability to extract the line-like objects and obtain their angular information by executing one convolution with the generated complex mask.

Future work includes studies on how different radial components or different orthogonal bases for angular component of the complex mask affect the filter properties and performance.

CMF$_2$ was successfully used for the extraction of palm blood vessels from images in a biometric system, in [3].