

Procesamiento Avanzado de Imágenes Astronómicas

Filtrado en Frecuencia

Fundamentos

- un número complejo y su conjugado:

$$C = R + jI$$

$$C^* = R - jI$$

- en coord. Polares:

$$C = |C|(\cos \theta + j \sin \theta)$$

$$|C| = \sqrt{R^2 + I^2}$$

$$\theta = \arctan(I/R)$$

- notación de Euler:

$$C = |C|e^{j\theta}$$

$$e^{j\theta} = \cos \theta + j \sin \theta$$

Fundamentos

- Transformada discreta de Fourier en 2D:

$$F(u, v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) e^{-j2\pi(ux/M + vy/N)}$$

- Transformada inversa:

$$f(x, y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u, v) e^{j2\pi(ux/M + vy/N)}$$

Fundamentos

- Algunas propiedades de la DFT:

$$f(x, y) e^{j2\pi(u_0 x/M + v_0 y/N)} \Leftrightarrow F(u - u_0, v - v_0)$$

$$f(x - x_0, y - y_0) \Leftrightarrow F(u, v) e^{-j2\pi(x_0 u/M + y_0 v/N)}$$

$$f(x, y) (-1)^{x+y} \Leftrightarrow F(u - M/2, v - N/2)$$

$$f(r, \theta + \theta_0) \Leftrightarrow F(\omega, \varphi + \theta_0)$$

Fundamentos

- Algunas propiedades de la DFT:

	Spatial Domain [†]		Frequency Domain [†]
1)	$f(x, y)$ real	\Leftrightarrow	$F^*(u, v) = F(-u, -v)$
2)	$f(x, y)$ imaginary	\Leftrightarrow	$F^*(-u, -v) = -F(u, v)$
3)	$f(x, y)$ real	\Leftrightarrow	$R(u, v)$ even; $I(u, v)$ odd
4)	$f(x, y)$ imaginary	\Leftrightarrow	$R(u, v)$ odd; $I(u, v)$ even
5)	$f(-x, -y)$ real	\Leftrightarrow	$F^*(u, v)$ complex
6)	$f(-x, -y)$ complex	\Leftrightarrow	$F(-u, -v)$ complex
7)	$f^*(x, y)$ complex	\Leftrightarrow	$F^*(-u - v)$ complex
8)	$f(x, y)$ real and even	\Leftrightarrow	$F(u, v)$ real and even
9)	$f(x, y)$ real and odd	\Leftrightarrow	$F(u, v)$ imaginary and odd
10)	$f(x, y)$ imaginary and even	\Leftrightarrow	$F(u, v)$ imaginary and even
11)	$f(x, y)$ imaginary and odd	\Leftrightarrow	$F(u, v)$ real and odd
12)	$f(x, y)$ complex and even	\Leftrightarrow	$F(u, v)$ complex and even
13)	$f(x, y)$ complex and odd	\Leftrightarrow	$F(u, v)$ complex and odd

Fundamentos

- Resumen de la DFT:

Name	Expression(s)
1) Discrete Fourier transform (DFT) of $f(x, y)$	$F(u, v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) e^{-j2\pi(ux/M+vy/N)}$
2) Inverse discrete Fourier transform (IDFT) of $F(u, v)$	$f(x, y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u, v) e^{j2\pi(ux/M+vy/N)}$
3) Polar representation	$F(u, v) = F(u, v) e^{j\phi(u, v)}$
4) Spectrum	$ F(u, v) = [R^2(u, v) + I^2(u, v)]^{1/2}$ $R = \text{Real}(F); \quad I = \text{Imag}(F)$
5) Phase angle	$\phi(u, v) = \tan^{-1} \left[\frac{I(u, v)}{R(u, v)} \right]$
6) Power spectrum	$P(u, v) = F(u, v) ^2$
7) Average value	$\bar{f}(x, y) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) = \frac{1}{MN} F(0, 0)$

Fundamentos

- Resumen de la DFT:

Name	Expression(s)
8) Periodicity (k_1 and k_2 are integers)	$F(u, v) = F(u + k_1M, v) = F(u, v + k_2N)$ $= F(u + k_1M, v + k_2N)$ $f(x, y) = f(x + k_1M, y) = f(x, y + k_2N)$ $= f(x + k_1M, y + k_2N)$
9) Convolution	$f(x, y) \star h(x, y) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f(m, n)h(x - m, y - n)$
10) Correlation	$f(x, y) \star h(x, y) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} f^*(m, n)h(x + m, y + n)$
11) Separability	<p>The 2-D DFT can be computed by computing 1-D DFT transforms along the rows (columns) of the image, followed by 1-D transforms along the columns (rows) of the result. See Section 4.11.1.</p>
12) Obtaining the inverse Fourier transform using a forward transform algorithm.	$MNf^*(x, y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F^*(u, v)e^{-j2\pi(ux/M+vy/N)}$ <p>This equation indicates that inputting $F^*(u, v)$ into an algorithm that computes the forward transform (right side of above equation) yields $MNf^*(x, y)$. Taking the complex conjugate and dividing by MN gives the desired inverse. See Section 4.11.2.</p>

Fundamentos

- Resumen de propiedades de la DFT:

Name	DFT Pairs
1) Symmetry properties	See Table 4.1
2) Linearity	$af_1(x, y) + bf_2(x, y) \Leftrightarrow aF_1(u, v) + bF_2(u, v)$
3) Translation (general)	$f(x, y)e^{j2\pi(u_0x/M+v_0y/N)} \Leftrightarrow F(u - u_0, v - v_0)$ $f(x - x_0, y - y_0) \Leftrightarrow F(u, v)e^{-j2\pi(ux_0/M+vy_0/N)}$
4) Translation to center of the frequency rectangle, $(M/2, N/2)$	$f(x, y)(-1)^{x+y} \Leftrightarrow F(u - M/2, v - N/2)$ $f(x - M/2, y - N/2) \Leftrightarrow F(u, v)(-1)^{u+v}$
5) Rotation	$f(r, \theta + \theta_0) \Leftrightarrow F(\omega, \varphi + \theta_0)$ $x = r \cos \theta \quad y = r \sin \theta \quad u = \omega \cos \varphi \quad v = \omega \sin \varphi$
6) Convolution theorem [†]	$f(x, y) \star h(x, y) \Leftrightarrow F(u, v)H(u, v)$ $f(x, y)h(x, y) \Leftrightarrow F(u, v) \star H(u, v)$

Fundamentos

- Resumen de propiedades de la DFT:

Name	DFT Pairs
7) Correlation theorem [†]	$f(x, y) \star h(x, y) \Leftrightarrow F^*(u, v) H(u, v)$ $f^*(x, y) h(x, y) \Leftrightarrow F(u, v) \star H(u, v)$
8) Discrete unit impulse	$\delta(x, y) \Leftrightarrow 1$
9) Rectangle	$\text{rect}[a, b] \Leftrightarrow ab \frac{\sin(\pi ua)}{(\pi ua)} \frac{\sin(\pi vb)}{(\pi vb)} e^{-j\pi(ua+vb)}$
10) Sine	$\sin(2\pi u_0 x + 2\pi v_0 y) \Leftrightarrow$ $j \frac{1}{2} [\delta(u + Mu_0, v + Nv_0) - \delta(u - Mu_0, v - Nv_0)]$
11) Cosine	$\cos(2\pi u_0 x + 2\pi v_0 y) \Leftrightarrow$ $\frac{1}{2} [\delta(u + Mu_0, v + Nv_0) + \delta(u - Mu_0, v - Nv_0)]$
<p>The following Fourier transform pairs are derivable only for continuous variables, denoted as before by t and z for spatial variables and by μ and ν for frequency variables. These results can be used for DFT work by sampling the continuous forms.</p>	
12) Differentiation (The expressions on the right assume that $f(\pm\infty, \pm\infty) = 0$.)	$\left(\frac{\partial}{\partial t}\right)^m \left(\frac{\partial}{\partial z}\right)^n f(t, z) \Leftrightarrow (j2\pi\mu)^m (j2\pi\nu)^n F(\mu, \nu)$ $\frac{\partial^m f(t, z)}{\partial t^m} \Leftrightarrow (j2\pi\mu)^m F(\mu, \nu); \frac{\partial^n f(t, z)}{\partial z^n} \Leftrightarrow (j2\pi\nu)^n F(\mu, \nu)$
13) Gaussian	$A 2\pi\sigma^2 e^{-2\pi^2\sigma^2(t^2+z^2)} \Leftrightarrow A e^{-(\mu^2+\nu^2)/2\sigma^2}$ (A is a constant)

Mecánica del filtrado

1. Given an input image $f(x, y)$ of size $M \times N$, obtain the padding parameters P and Q from Eqs. (4.6-31) and (4.6-32). Typically, we select $P = 2M$ and $Q = 2N$.
2. Form a padded image, $f_p(x, y)$, of size $P \times Q$ by appending the necessary number of zeros to $f(x, y)$.
3. Multiply $f_p(x, y)$ by $(-1)^{x+y}$ to center its transform.
4. Compute the DFT, $F(u, v)$, of the image from step 3.
5. Generate a real, symmetric filter function, $H(u, v)$, of size $P \times Q$ with center at coordinates $(P/2, Q/2)$.[†] Form the product $G(u, v) = H(u, v)F(u, v)$ using array multiplication; that is, $G(i, k) = H(i, k)F(i, k)$.
6. Obtain the processed image:

$$g_p(x, y) = \left\{ \text{real} \left[\mathfrak{F}^{-1} [G(u, v)] \right] \right\} (-1)^{x+y}$$

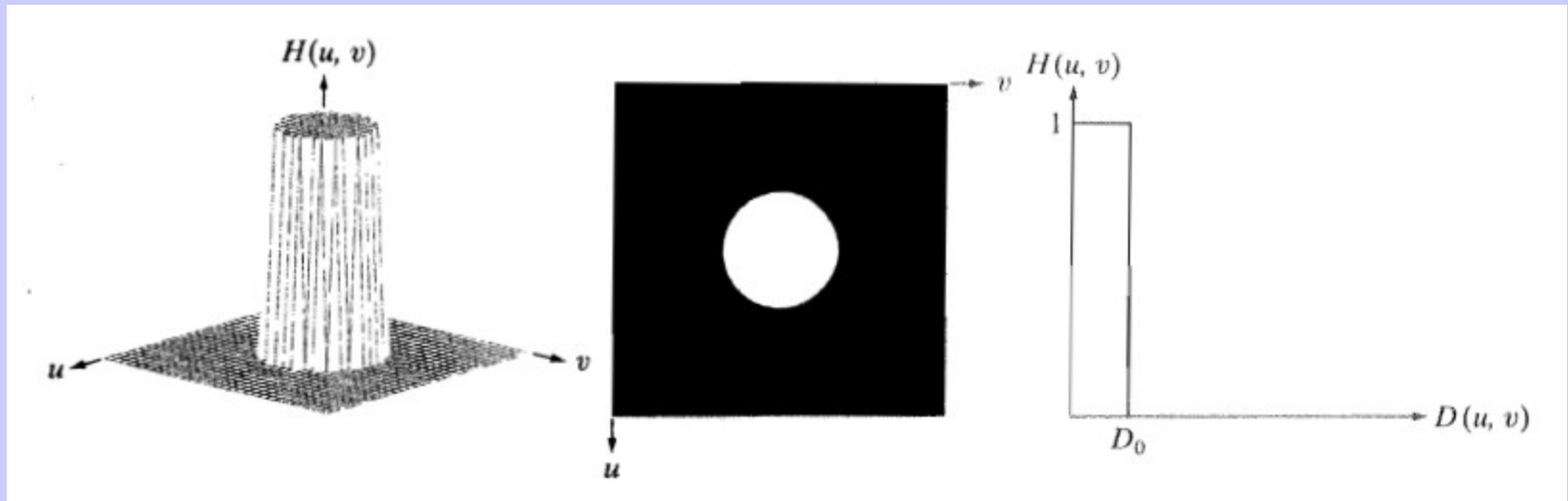
where the real part is selected in order to ignore parasitic complex components resulting from computational inaccuracies, and the subscript p indicates that we are dealing with padded arrays.

7. Obtain the final processed result, $g(x, y)$, by extracting the $M \times N$ region from the top, left quadrant of $g_p(x, y)$.

Filtros pasabajos

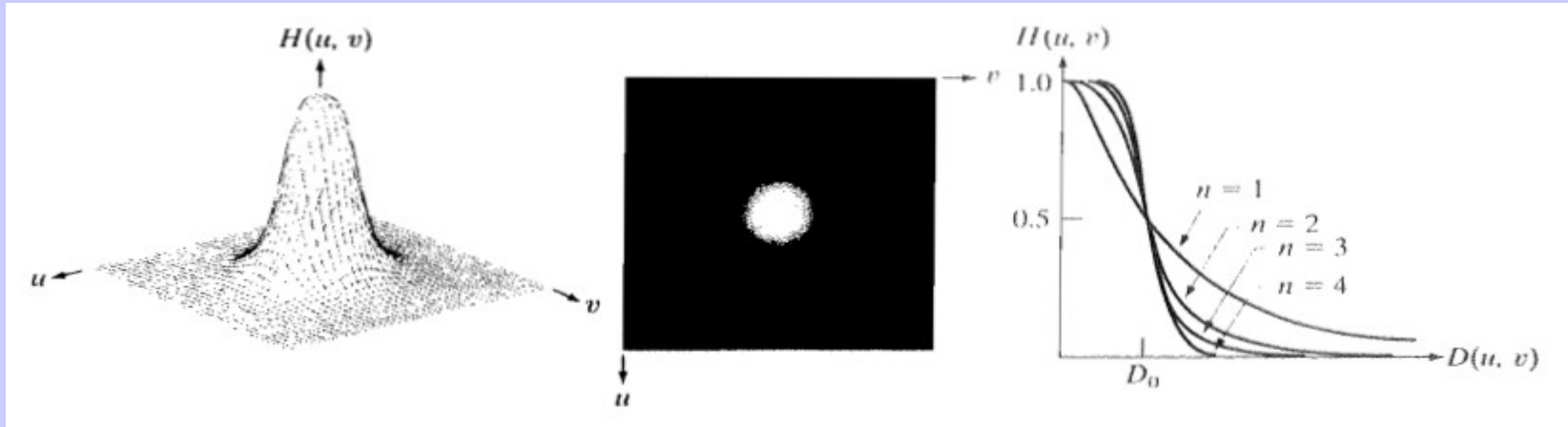
Ideal	Butterworth	Gaussian
$H(u, v) = \begin{cases} 1 & \text{if } D(u, v) \leq D_0 \\ 0 & \text{if } D(u, v) > D_0 \end{cases}$	$H(u, v) = \frac{1}{1 + [D(u, v)/D_0]^{2n}}$	$H(u, v) = e^{-D^2(u, v)/2D_0^2}$

- Pasabajos Ideal:

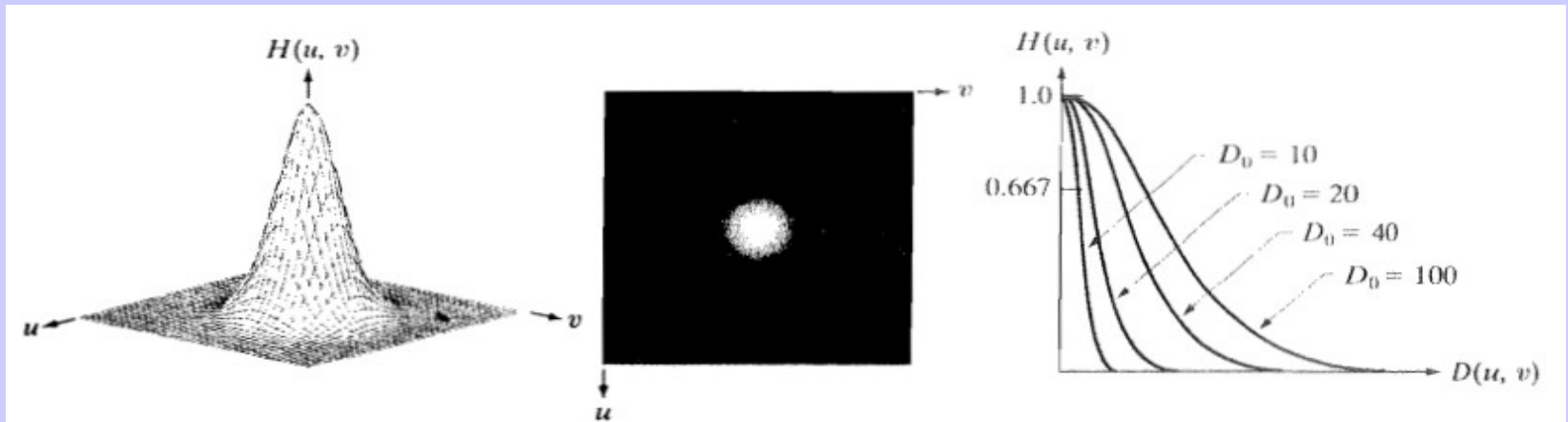


Filtros pasabajos

- Butterworth de orden n :



- Gaussiano:



Filtros pasaaltos

Ideal	Butterworth	Gaussian
$H(u, v) = \begin{cases} 0 & \text{if } D(u, v) \leq D_0 \\ 1 & \text{if } D(u, v) > D_0 \end{cases}$	$H(u, v) = \frac{1}{1 + [D_0/D(u, v)]^{2n}}$	$H(u, v) = 1 - e^{-D^2(u, v)/2D_0^2}$

- Laplaciano:

$$H(u, v) = -4\pi^2(u^2 + v^2)$$

$$\begin{aligned} H(u, v) &= -4\pi^2[(u - P/2)^2 + (v - Q/2)^2] \\ &= -4\pi^2 D^2(u, v) \end{aligned}$$

Filtros pasabanda

- Utilizando una cota doble se pueden crear filtros pasabanda de diferente tipo:

Ideal	Butterworth	Gaussian
$H(u, v) = \begin{cases} 0 & \text{if } D_0 - \frac{W}{2} \leq D \leq D_0 + \frac{W}{2} \\ 1 & \text{otherwise} \end{cases}$	$H(u, v) = \frac{1}{1 + \left[\frac{DW}{D^2 - D_0^2} \right]^{2n}}$	$H(u, v) = 1 - e^{-\left[\frac{D^2 - D_0^2}{DW} \right]^2}$

Filtro homomórfico

- Supongamos que tenemos una imagen que es el resultado del producto de dos componentes:

$$i(x, y) = l(x, y)r(x, y)$$

- no es posible operar en frecuencia sobre las componentes de esta imagen porque la transformada de un producto no es el producto de las transformadas.

Filtro homomórfico

- una forma de operar es tomando logaritmos a ambos lados:

$$\ln[i(x, y)] = \ln[l(x, y)] + \ln[r(x, y)]$$

- para después aplicar la transformada:

$$I(\ln[i(x, y)]) = L(\ln[l(x, y)]) + R(\ln[r(x, y)])$$

$$I(u, v) = L(u, v) + R(u, v)$$

Filtro homomórfico

- si ahora aplicamos un filtro H , tenemos:

$$G(u, v) = H(u, v)I(u, v) = H(u, v)L(u, v) + H(u, v)R(u, v)$$

- si se diseña el filtro de tal modo que opere sobre alguna de las componentes en forma preferencial estaremos actuando para incrementarla o disminuirla respecto a la otra.

Filtro homomórfico

- para recuperar la imagen en el dominio espacial:

$$g(x, y) = \mathcal{T}^{-1}[H(u, v)I(u, v)] = \mathcal{T}^{-1}[H(u, v)L(u, v)] + \mathcal{T}^{-1}[H(u, v)R(u, v)]$$

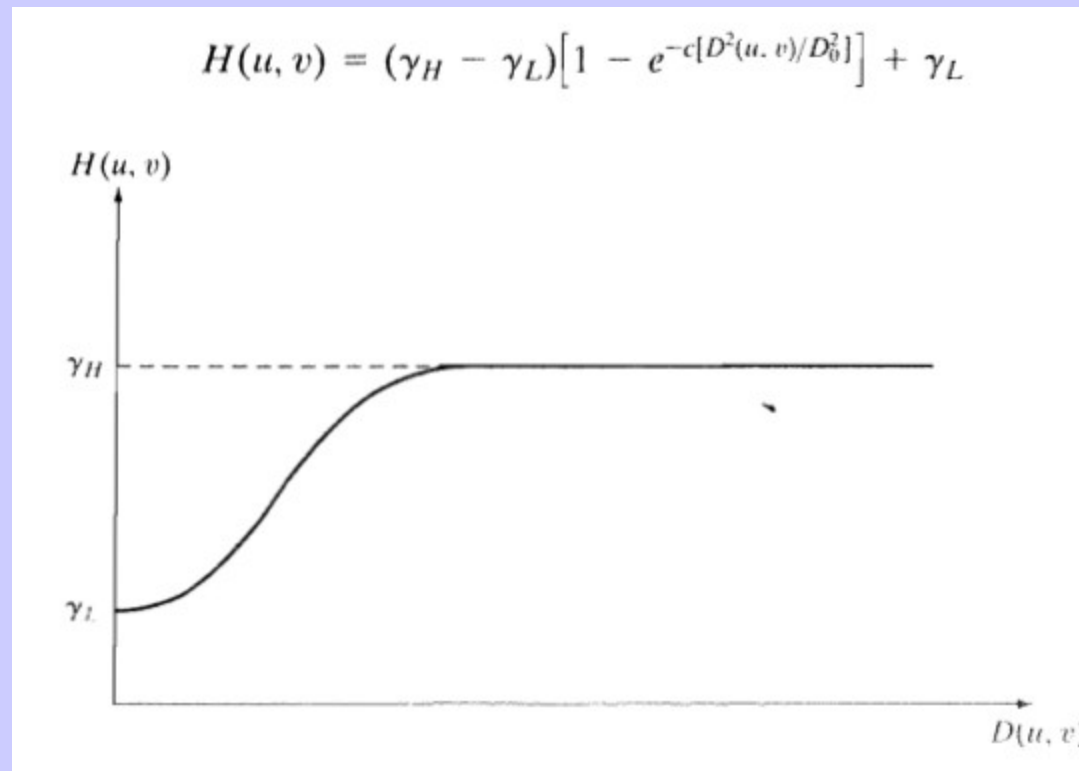
$$g(x, y) = l'(x, y) + r'(x, y)$$

- pero para regresar al modo inicial hay que obtener la exponencial:

$$i'(x, y) = \exp[g(x, y)] = \exp[l'(x, y)] \exp[r'(x, y)] = l''(x, y)r''(x, y)$$

Filtro homomórfico

- el filtro H se denomina *filtro homomórfico* y existen varias formas de él.
- un ejemplo posible es (iluminación – reflexión):



donde γ_L y γ_R
son
coeficientes
de tal modo
que su suma
valga 1

