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Appendix A

The Fourier Transform and 3D Affine Deformations

In this section, we demonstrate the effect of a spatial 3D affine deformation on the Fourier representation of an object. Suppose that $f(\mathbf{x}) = f(x, y, z)$ has a 3D Fourier transform $F(\mathbf{u}) = F(u, v, w)$. The 3D affine transformation of f can be defined for points $\mathbf{x} \in f$ by

$$\mathcal{A}(\mathbf{x}) = \mathbf{A}.\mathbf{x} + \mathbf{t}\ . \tag{A.1}$$

where $\mathbf{A}$ is a 3x3 matrix, and $\mathbf{t}$ is a 3x1 translation vector (see Section 2.1.1). If $g(\mathbf{x})$ is the 3D affine transformation of $f(\mathbf{x})$ then

$$g(\mathbf{x}) = f\Big(\mathbf{A}^{-1}(\mathbf{x} - \mathbf{t})\Big) \tag{A.2}$$

The Fourier transform of $g(\mathbf{x})$ can be written as

$$G(\mathbf{u}) = \iiint_{-\infty}^{\infty} f\Big(\mathbf{A}^{-1}(\mathbf{x} - \mathbf{t})\Big) e^{-i2\pi(\mathbf{u}\cdot\mathbf{x})} d\mathbf{x} \tag{A.3}$$

Making the substitution of variables $\hat{\mathbf{x}} = \mathbf{A}^{-1}(\mathbf{x} - \mathbf{t})$, and since $d\hat{\mathbf{x}} = |\det(\mathbf{A}^{-1})|\ d\mathbf{x}$ we obtain

$$G(\mathbf{u}) = \frac{1}{|\det(\mathbf{A}^{-1})|} \iiint_{-\infty}^{\infty} f(\hat{\mathbf{x}}) e^{-i2\pi(\mathbf{u}\cdot(\mathbf{A}\hat{\mathbf{x}}+\mathbf{t}))} d\hat{\mathbf{x}} \tag{A.4}$$

$$= \frac{e^{-i2\pi(\mathbf{u}\cdot\mathbf{t})}}{|\det(\mathbf{A}^{-1})|} \iiint_{-\infty}^{\infty} f(\hat{\mathbf{x}}) e^{-i2\pi(\mathbf{u}\cdot\mathbf{A}\hat{\mathbf{x}})} d\hat{\mathbf{x}} \tag{A.5}$$

$$= \frac{e^{-i2\pi(\mathbf{u}\cdot\mathbf{t})}}{|\det(\mathbf{A}^{-1})|} \iiint_{-\infty}^{\infty} f(\hat{\mathbf{x}}) e^{-i2\pi(\mathbf{A}^T\mathbf{u}\cdot\hat{\mathbf{x}})} d\hat{\mathbf{x}} \tag{A.6}$$

$$= \frac{e^{-i2\pi(\mathbf{u}\cdot\mathbf{t})}}{|\det(\mathbf{A}^{-1})|} F(\mathbf{A}^T\mathbf{u}) \tag{A.7}$$

To write the inverse mapping, make the variable substitution $\hat{\mathbf{u}} = \mathbf{A}^T\mathbf{u}$,

$$G(\mathbf{A}^{-T}\hat{\mathbf{u}}) = \frac{e^{-i2\pi(\mathbf{A}^{-T}\hat{\mathbf{u}}\cdot\mathbf{t})}}{|\det(\mathbf{A}^{-1})|} F(\hat{\mathbf{u}})\ , \tag{A.8}$$

so that

$$F(\hat{\mathbf{u}}) = \frac{e^{i2\pi(\mathbf{A}^{-T}\hat{\mathbf{u}}\cdot\mathbf{t})}}{|\det(\mathbf{A})|} G(\mathbf{A}^{-T}\hat{\mathbf{u}}). \tag{A.9}$$

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EXPERIENCE

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- Tau Beta Pi, Engineering Honor Society, 1996-1997.
- JHU Provost's Undergraduate Research Award, 1995

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