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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

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

Vita

EDUCATION

Johns Hopkins University, Baltimore, Maryland USA

- Ph.D., Biomedical Engineering, 1996-2003
- B.S., Biomedical Engineering, 1993-1996
- B.A., Computer Science, 1993-1996

EXPERIENCE

- **Research Engineer** 05/2001 - 01/2002
  INRIA (National Research Institute for Computer Science and Control)
  Sophia Antipolis, France
  - Member of the Chir (Surgical Robotics) group
  - Developed an algorithm for 3D motion tracking of coronary arteries in x–ray biplane cineangiograms
- **Pre-doctoral Research Fellow** 2000 - 2003
  Laboratory of Cardiac Energetics, NHLBI, NIH, DHHS
  Bethesda, MD, USA
  - "Respiratory Motion of the Heart: Implications for MR Imaging"
  - Primary advisor: Elliot R. McVeigh

- **Graduate Student and Teaching Assistant** 1996 - 2003
  Department of Biomedical Engineering, Johns Hopkins School of Medicine
  Baltimore, MD, USA
  - Developed a visualization and interactive template-based segmentation tool for medical images
  - Conducted weekly review sessions as a teaching assistant for: Honors C Programming (1995); Intermediate Programming in C++ (1996); Magnetic Resonance in Medicine (1998); and Physiologic Foundations in Biomedical Engineering (1999)
- **Undergraduate Research Assistant** 1994 - 1996
  Department of Biomedical Engineering, Johns Hopkins School of Medicine
  Baltimore, MD, USA
  - "Computer aided navigation through parameter space: A case study using the incremental model for calcium release by the IP_3 receptor"
  - Primary advisor: Robert D. Phair

HONORS AND AWARDS

- NIH Fellows Award for Research Excellence, 2003
- NIH Pre-IRTA Fellowship, 2000-2003
- ISMRM Student Stipend Award, 1999
- HHMI Predoctoral Fellowship, Honorable mention, 1997
- Whitaker Foundation, Graduate Fellowship, 1997-2000
- JHU Biomedical Engineering Undergraduate Research Award, 1996
- JHU Computer Science Outstanding Double Major Award, 1996
- Tau Beta Pi, Engineering Honor Society, 1996-1997.
- JHU Provost's Undergraduate Research Award, 1995

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