Errata to First Printing: Numerical Simulation of Optical Wave Propagation Jason D. Schmidt

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1 Chapter 1

p. 5, Eq. (1.22) : $\mathbf{D} = \epsilon_0 (1 + \chi_m) \mathbf{E}$ should be $\mathbf{D} = \epsilon_0 (1 + \chi_e) \mathbf{E}$

p. 10, Eq. (1.60):

$$U(x_2, y_2) = \frac{e^{ik\Delta z}}{2i} \left\{ [C(\alpha_2) - C(\alpha_1)]^2 + i [S(\alpha_2) - S(\alpha_1)]^2 \times [C(\beta_2) - C(\beta_1)]^2 + i [S(\beta_2) - S(\beta_1)]^2 \right\},$$

should be

$$U(x_2, y_2) = \frac{e^{ik\Delta z}}{2i} \left\{ [C(\alpha_2) - C(\alpha_1)] + i [S(\alpha_2) - S(\alpha_1)] \times [C(\beta_2) - C(\beta_1)] + i [S(\beta_2) - S(\beta_1)] \right\},$$

p. 11, second line above Eq. (1.67): There is a period missing after "field[5]";

p. 11, Eq. (1.67):

$$U(x_2, y_2) = \frac{e^{ik\Delta z}}{i\lambda\Delta z} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} U(x_1, y_1) e^{i \frac{k}{2\Delta z}(x_1 x_2 + y_1 y_2)} dx_1 \, dy_1.$$

should be

$$U\left(x_2, y_2\right) = \frac{e^{ik\Delta z} e^{i\frac{k}{2\Delta z}\left(x_2^2+y_2^2\right)}}{i\lambda\Delta z} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} U\left(x_1, y_1\right) e^{-i\frac{k}{\Delta z}\left(x_1 x_2 + y_1 y_2\right)}\, dx_1 dy_1.$$

p. 12, Eqs. (1.69)–(1.71):

$$\begin{aligned} U\left(x_2, y_2\right) &= \frac{e^{ik\Delta z}}{i\lambda\Delta z} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} \left[\operatorname{rect}\left(\frac{x_1 - \Delta x/2}{D_x}\right) + \operatorname{rect}\left(\frac{x_1 + \Delta x/2}{D_x}\right)\right] \\ &\quad \times \operatorname{rect}\left(\frac{y_1}{D_y}\right) e^{i\frac{k}{2\Delta z}\left(x_1 x_2 + y_1 y_2\right)}\, dx_1 dy_1 \\ &= \frac{e^{ik\Delta z}}{i\lambda\Delta z} \left[\int\limits_{-(\Delta x + D_x)/2}^{(-\Delta x + D_x)/2} e^{i\frac{k}{2\Delta z} x_1 x_2}\, dx_1 + \int\limits_{(\Delta x - D_x)/2}^{(\Delta x + D_x)/2} e^{i\frac{k}{2\Delta z} x_1 x_2}\, dx_1\right] \\ &\quad \times \int\limits_{-D_y/2}^{D_y/2} e^{i\frac{k}{2\Delta z} y_1 y_2}\, dy_1 \\ &= e^{ik\Delta z} \frac{2 D_x D_y}{\lambda\Delta z} \sin\left(\frac{\pi\Delta x\, x_2}{2\lambda\Delta z}\right) \operatorname{sinc}\left(\frac{D_x x_2}{2\lambda\Delta z}\right) \operatorname{sinc}\left(\frac{D_y y_2}{2\lambda\Delta z}\right). \end{aligned}$$

should be

$$\begin{aligned} U\left(x_2, y_2\right) &= \frac{e^{ik\Delta z} e^{i\frac{k}{2\Delta z}\left(x_2^2+y_2^2\right)}}{i\lambda\Delta z} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} \left[\operatorname{rect}\left(\frac{x_1 - \Delta x/2}{D_x}\right) + \operatorname{rect}\left(\frac{x_1 + \Delta x/2}{D_x}\right)\right] \\ &\quad \times \operatorname{rect}\left(\frac{y_1}{D_y}\right) e^{-i\frac{k}{\Delta z}\left(x_1 x_2 + y_1 y_2\right)}\, dx_1 dy_1 \\ &= \frac{e^{ik\Delta z} e^{i\frac{k}{2\Delta z}\left(x_2^2+y_2^2\right)}}{i\lambda\Delta z} \left[\int\limits_{-(\Delta x + D_x)/2}^{(-\Delta x + D_x)/2} e^{-i\frac{k}{\Delta z} x_1 x_2}\, dx_1 + \int\limits_{(\Delta x - D_x)/2}^{(\Delta x + D_x)/2} e^{-i\frac{k}{\Delta z} x_1 x_2}\, dx_1\right] \\ &\quad \times \int\limits_{-D_y/2}^{D_y/2} e^{-i\frac{k}{\Delta z} y_1 y_2}\, dy_1 \\ &= e^{ik\Delta z} e^{i\frac{k}{2\Delta z}\left(x_2^2+y_2^2\right)} \frac{2 D_x D_y}{i\lambda\Delta z} \cos\left(\frac{\pi\Delta x\, x_2}{\lambda\Delta z}\right) \operatorname{sinc}\left(\frac{D_x x_2}{\lambda\Delta z}\right) \operatorname{sinc}\left(\frac{D_y y_2}{\lambda\Delta z}\right). \end{aligned}$$

p. 12, problem 4: "cylindrical" should be "spherical"

2 Chapter 2

p. 17, Eq. (2.6): $G_{m'} = \delta \sum_{n=1}^{N} g_{k'} e^{-i2\pi(m'-1)(n'-1)/N}$ should be $G_{m'} = \delta \sum_{n'=1}^{N} g_{n'} e^{-i2\pi(m'-1)(n'-1)/N}$

p. 21, sixth line below Eq. (2.10): "gray squares" should be "black ×'s"

3 Chapter 3

4 Chapter 4

p. 56, last line: "monochramatic" should be "monochromatic"

p. 58, Figure 4.1: The plot actually shows irradiance (see last two pages of this errata sheet).

p. 59, Eq. (4.11):

$$U(x_2, y_2) = \frac{1}{i\lambda f_l} e^{i\frac{k}{2f}\left(1-\frac{d}{f_l}\right)\left(x_2^2+y_2^2\right)} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} t_A(x_1, y_1) \times P\left(x_1 + \frac{d}{f_l}x_2, y_1 + \frac{d}{f_l}y_2\right) e^{-i\frac{2\pi}{\lambda f_l}(x_2x_1+y_2y_1)}\, dx_1\, dy_1,$$

should be

$$U(x_2, y_2) = \frac{1}{i\lambda f_l} e^{i\frac{k}{2f_l}\left(1-\frac{d}{f_l}\right)\left(x_2^2+y_2^2\right)} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} t_A(x_1, y_1) \times P\left(x_1 + \frac{d}{f_l}x_2, y_1 + \frac{d}{f_l}y_2\right) e^{-i\frac{2\pi}{\lambda f_l}(x_2x_1+y_2y_1)}\, dx_1\, dy_1,$$

p. 62, Listing 4.4: In line 17, `.* exp(i * k/(2*f)) * (1-d/f) * (u.^2 + v.^2)` should be `.* exp(i * k/(2*f)) * (1-d/f) * (x2.^2 + y2.^2)`

p. 62, Eqs. (4.15)–(4.16): There are two equation numbers assigned to a one equation. There should be only one equation number.

p. 62, Eqs. (4.15)–(4.16):

$$U(x_2, y_2) = \frac{f_l}{d}\frac{1}{i\lambda d}e^{i\frac{k}{2d}\left(x_2^2+y_2^2\right)} \times \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} t_A(x_1, y_1)\, P\left(x_1\frac{d}{f_l}, y_1\frac{d}{f_l}\right) e^{-i\frac{2\pi}{\lambda d}(x_2x_1+y_2y_1)}\, dx_1\, dy_1.$$

should be

$$U(x_2, y_2) = \frac{f_l}{d}\frac{1}{i\lambda d}e^{i\frac{k}{2d}\left(x_2^2+y_2^2\right)} \times \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} t_A(x_1, y_1)\, P\left(\frac{f_l}{d}x_1, \frac{f_l}{d}y_1\right) e^{-i\frac{2\pi}{\lambda d}(x_2x_1+y_2y_1)}\, dx_1\, dy_1.$$

p. 62, Eq. (4.17):

$$U(x_2, y_2) = \frac{f_l}{d}\frac{1}{i\lambda d}e^{i\frac{k}{2d}\left(x_2^2+y_2^2\right)}\mathcal{F}\left\{t_A(x_1, y_1)\, P\left(x_1\frac{d}{f_l}, y_1\frac{d}{f_l}\right)\right\}\Bigg|_{f_x=\frac{x_2}{\lambda d}, f_y=\frac{y_2}{\lambda d}}.$$

should be

$$U(x_2, y_2) = \frac{f_l}{d}\frac{1}{i\lambda d}e^{i\frac{k}{2d}\left(x_2^2+y_2^2\right)}\mathcal{F}\left\{t_A(x_1, y_1)\, P\left(\frac{f_l}{d}x_1, \frac{f_l}{d}y_1\right)\right\}\Bigg|_{f_x=\frac{x_2}{\lambda d}, f_y=\frac{y_2}{\lambda d}}.$$

p. 63, Listing 4.5: In line 17, `.* exp(i * k/(2*d)) * (u.^2 + v.^2) .* ft2(Uin, d1)` should be `{.* exp(i * k/(2*d)) * (x2.^2 + y2.^2) .* ft2(Uin, d1)`

5 Chapter 5

p. 80, two lines below Eq. (5.36): "to yield the the diffraction image" should be "to yield the diffraction image"

p. 83, second line: "unaberrated point spread function" should be "unaberrated pupil function"

6 Chapter 6

p. 88, Eq. (6.1):

$$U(x_2, y_2) = \frac{e^{ikz}}{i\lambda\Delta z} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} U(x_1, y_1)\, e^{i\frac{k}{2\Delta z}\left[(x_2-x_1)^2+(y_2-y_1)^2\right]}\, dx_1\, dy_1$$

should be

$$U(x_2, y_2) = \frac{e^{ik\Delta z}}{i\lambda\Delta z} \int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} U(x_1, y_1)\, e^{i\frac{k}{2\Delta z}\left[(x_2-x_1)^2+(y_2-y_1)^2\right]}\, dx_1\, dy_1$$

p. 90, Eq. (6.13):

$$\mathcal{Q}_2[d, \mathbf{r}] = \mathcal{Q}\left[\frac{4\pi^2}{k} d, \mathbf{r}\right]$$

should be

$$\mathcal{Q}_2[d, \mathbf{r}] = \mathcal{Q}\left[\frac{4\pi^2}{k^2} d, \mathbf{r}\right]$$

p. 93, Eq. (6.17):

$$U(\mathbf{r}_2) = \mathcal{R}[\Delta z_2, \mathbf{r}_{1a}, \mathbf{r}_2]\, \mathcal{R}[\Delta z_1, \mathbf{r}_1, \mathbf{r}_{1a}]\, \{U(\mathbf{r}_1, \mathbf{r}_{1a})\}$$

should be

$$U(\mathbf{r}_2) = \mathcal{R}[\Delta z_2, \mathbf{r}_{1a}, \mathbf{r}_2]\, \mathcal{R}[\Delta z_1, \mathbf{r}_1, \mathbf{r}_{1a}]\, \{U(\mathbf{r}_1)\}$$

p. 100, Eq. (6.57):

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = r^2 - 2\mathbf{r}_2 \cdot \mathbf{r}_1 + r_1^2$$

should be

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = r_2^2 - 2\mathbf{r}_2 \cdot \mathbf{r}_1 + r_1^2$$

p. 100, Eq. (6.62):

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = -m\left|\frac{r_2}{m} + r_1\right|^2 + \left(\frac{1+m}{m}\right) r_2^2 + (1+m)\, r_1^2.$$

should be

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = -m \left|\frac{\mathbf{r}_2}{m} + \mathbf{r}_1\right|^2 + \left(\frac{1+m}{m}\right) r_2^2 + (1+m)\, r_1^2.$$

p. 100, Eq. (6.63):

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = m' \left|\frac{r_2}{-m'} + r_1\right|^2 + \left(\frac{1-m'}{-m'}\right) r_2^2 + (1-m')\, r_1^2$$

should be

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = m' \left|\frac{\mathbf{r}_2}{-m'} + \mathbf{r}_1\right|^2 + \left(\frac{1-m'}{-m'}\right) r_2^2 + (1-m')\, r_1^2$$

p. 100, Eq. (6.64):

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = m' \left|\frac{\mathbf{r}_2}{m'} - \mathbf{r}_1\right|^2 - \left(\frac{1-m'}{m'}\right) r^2 + (1-m')\, r_1^2,$$

should be

$$|\mathbf{r}_2 - \mathbf{r}_1|^2 = m' \left|\frac{\mathbf{r}_2}{m'} - \mathbf{r}_1\right|^2 - \left(\frac{1-m'}{m'}\right) r_2^2 + (1-m')\, r_1^2,$$

p. 101, fifth line from the bottom: "Figure 6.4 shows" should be "Figure 6.5 shows."

p. 103, Eq. (6.72):

$$\begin{pmatrix} y_2 \\ n_2\, y_2' \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{n_2 - n_1}{R} & 1 \end{pmatrix} \begin{pmatrix} y_1 \\ n_1\, y_1' \end{pmatrix},$$

should be

$$\begin{pmatrix} y_2 \\ n_2\, y_2' \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{n_1 - n_2}{R} & 1 \end{pmatrix} \begin{pmatrix} y_1 \\ n_1\, y_1' \end{pmatrix},$$

p. 103, Eq. (6.73):

$$\mathsf{S} = \begin{pmatrix} 1 & 0 \\ \frac{1-n}{R_2} & 1 \end{pmatrix} \begin{pmatrix} 1 & \Delta z/n \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ \frac{n-1}{R_1} & 1 \end{pmatrix}$$

should be

$$\mathsf{S} = \begin{pmatrix} 1 & 0 \\ \frac{n-1}{R_2} & 1 \end{pmatrix} \begin{pmatrix} 1 & \Delta z/n \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ \frac{1-n}{R_1} & 1 \end{pmatrix}$$

p. 104, sixth line above Eq. (6.78): "much like in Eq. (4.8)" should be "much like in Eq. (4.9)."

p. 105, fourth line from the bottom: "Figure 6.4 shows" should be "Figure 6.6 shows"

p. 108, Figure 6.7: In the y label, "[MW/m^2]" should be "[kW/m^2]"

p. 110, Eq, (6.91):

$$\widetilde{U}_{pt}\left(\mathbf{r}_1\right) = A\, e^{-i\frac{k}{2\Delta z}r_1^2} e^{i\frac{k}{2\Delta z}r_c^2} \mathcal{F}^{-1}\left\{\mathrm{rect}\left(\frac{\lambda\Delta z f_x - x_c}{D}\right)\mathrm{rect}\left(\frac{\lambda\Delta z f_y - y_c}{D}\right)\right\}$$

should be

$$\begin{aligned}\widetilde{U}_{pt}\left(\mathbf{r}_1\right) &= A\, e^{-i\frac{k}{2\Delta z}r_1^2} e^{i\frac{k}{2\Delta z}r_c^2} \\ &\times \mathcal{F}^{-1}\left\{\mathrm{rect}\left(\frac{\lambda\Delta z f_x - x_c}{D}\right)\mathrm{rect}\left(\frac{\lambda\Delta z f_y - y_c}{D}\right) e^{-i2\pi\mathbf{r}_c\cdot\mathbf{f}_1}\right\}\end{aligned}$$

p. 111, Figure 6.10: In the y label, "[MW/m^2]" should be "[kW/m^2]"

7 Chapter 7

p. 116, second line below Eq. (7.3): $\left(\alpha\hat{i} + \beta\hat{j} + \gamma\hat{k}\right)$ should be $\left(\alpha\hat{\mathbf{i}} + \beta\hat{\mathbf{j}} + \gamma\hat{\mathbf{k}}\right)$

p. 116, Eq. (7.4):

$$U_p\left(x, y, z, t\right) = e^{i\mathbf{k}\cdot\mathbf{r}} = e^{i\frac{2\pi}{\lambda}(\alpha x + \beta y)} e^{i\frac{2\pi}{\lambda}\gamma z}.$$

should be

$$U_p\left(x, y, z\right) = e^{i\mathbf{k}\cdot\mathbf{r}} = e^{i\frac{2\pi}{\lambda}(\alpha x + \beta y)} e^{i\frac{2\pi}{\lambda}\gamma z}.$$

p. 126, just below Eq. (7.57): $f'_{1x} = \pm 1/\left(2\delta_1\right)$ should be $f_{1x} = \pm 1/\left(2\delta_1\right)$

8 Chapter 8

p. 138, Eq. (8.16):

$$U(\mathbf{r}_3) = \mathcal{Q}\left[\frac{m_2-1}{m_2\,\Delta z_2}, \mathbf{r}_3\right] \mathcal{F}^{-1}\left[\mathbf{f}_2, \frac{\mathbf{r}_3}{m_2}\right] \mathcal{Q}_2\left[-\frac{\Delta z_2}{m_2}, \mathbf{f}_2\right] \mathcal{F}\left[\mathbf{r}_2, \mathbf{f}_2\right] \frac{1}{m_2}$$
$$\times \mathcal{A}\left[\mathbf{r}_2\right] \mathcal{F}^{-1}\left[\mathbf{f}_1, \frac{\mathbf{r}_2}{m_1}\right] \mathcal{Q}_2\left[-\frac{\Delta z}{m_1}, \mathbf{f}_1\right] \mathcal{F}\left[\mathbf{r}_1, \mathbf{f}_1\right] \mathcal{Q}\left[\frac{1-m_1}{\Delta z_1}, \mathbf{r}_1\right] \frac{1}{m_1}\left\{U(\mathbf{r}_1)\right\}.$$

should be

$$U(\mathbf{r}_3) = \mathcal{Q}\left[\frac{m_2-1}{m_2\,\Delta z_2}, \mathbf{r}_3\right] \mathcal{F}^{-1}\left[\mathbf{f}_2, \frac{\mathbf{r}_3}{m_2}\right] \mathcal{Q}_2\left[-\frac{\Delta z_2}{m_2}, \mathbf{f}_2\right] \mathcal{F}\left[\mathbf{r}_2, \mathbf{f}_2\right] \frac{1}{m_2}$$
$$\times \mathcal{A}\left[\mathbf{r}_2\right] \mathcal{F}^{-1}\left[\mathbf{f}_1, \frac{\mathbf{r}_2}{m_1}\right] \mathcal{Q}_2\left[-\frac{\Delta z_1}{m_1}, \mathbf{f}_1\right] \mathcal{F}\left[\mathbf{r}_1, \mathbf{f}_1\right] \mathcal{Q}\left[\frac{1-m_1}{\Delta z_1}, \mathbf{r}_1\right] \frac{1}{m_1}\left\{U(\mathbf{r}_1)\right\}.$$

p. 143, Eq. (8.20):

$$\left(1+\frac{\Delta z_1}{R}\right)\delta_1 \frac{\lambda \Delta z_1}{D_1} \le \delta_2 \le \left(1+\frac{\Delta z_1}{R}\right)\delta_1 + \frac{\lambda \Delta z_1}{D_1}.$$

should be

$$\left(1+\frac{\Delta z_1}{R}\right)\delta_1 - \frac{\lambda \Delta z_1}{D_1} \le \delta_2 \le \left(1+\frac{\Delta z_1}{R}\right)\delta_1 + \frac{\lambda \Delta z_1}{D_1}.$$

p. 143, inequality 2:
$N \ge \frac{D_1}{2\delta_1} + \frac{D_n}{2\delta_n} + \frac{\lambda \Delta z}{2\delta_1 \delta_n}$
should be
$N \ge \frac{D_1}{2\delta_1} + \frac{D_2}{2\delta_n} + \frac{\lambda \Delta z}{2\delta_1 \delta_n}$

p. 145, Figure 8.6: The figure was generated based on a propagation distance of $\Delta z = 1$ m, but it should be based on $\Delta z = 2$ m

p. 146, Listing 8.2, line 7:
```
z = 1;     % propagation distance [m]
```
should be
```
z = 2;     % propagation distance [m]
```

9 Chapter 9

p. 153, Eq. (9.6):

$$D_v(r) = C_v^2\, l_0^{-4/3}\, r^2,$$

should be

$$D_v(r) = C_v^2\, l_0^{-4/3}\, r^2.$$

p. 155, in the line below Eq. (9.16):

$\kappa = 2\pi\left(f_x\hat{\mathbf{i}} + f_y\hat{\mathbf{j}}\right)$
should be
$\boldsymbol{\kappa} = 2\pi\left(f_x\hat{\mathbf{i}} + f_y\hat{\mathbf{j}}\right)$

p. 159, Eq. (9.37):

$$\mu(|\Delta\mathbf{r}|, z) = \exp\left\{-4\pi^2 k^2 \int_0^{\Delta z}\int_0^{\infty} \Phi_n(\kappa, z)\left[1 - J_0(\kappa|\Delta\mathbf{r}|)\right] d\kappa dz\right\},$$

should be

$$\mu(|\Delta\mathbf{r}|, \Delta z) = \exp\left\{-4\pi^2 k^2 \int_0^{\Delta z}\int_0^{\infty} \Phi_n(\kappa, z)\left[1 - J_0(\kappa|\Delta\mathbf{r}|)\right] \kappa\, d\kappa dz\right\},$$

p. 159, Eq. (9.38):

$$\mu^K(|\Delta\mathbf{r}|, z) = \exp\left[-1.46k^2|\Delta\mathbf{r}|^{5/3}\int_0^{\Delta z} C_n^2(z)\, dz\right]$$

should be

$$\mu^K(|\Delta\mathbf{r}|, \Delta z) = \exp\left[-1.46k^2|\Delta\mathbf{r}|^{5/3}\int_0^{\Delta z} C_n^2(z)\, dz\right]$$

p. 159, Eq. (9.40):

$$\rho_0 = -1.46k^2|\Delta\mathbf{r}|^{5/3}\int_0^{\Delta z} C_n^2(z)\, dz$$

should be

$$\rho_0 = \left[1.46k^2 \int_0^{\Delta z} C_n^2(z)\ dz \right]^{-3/5}.$$

p. 160, third line:
With these definitions,
should be
With these definitions and letting $r = |\Delta \mathbf{r}|$,

p. 160, Eq. (9.44):

$$D^K(|\Delta \mathbf{r}|) = 6.88 \left(\frac{r}{r_0} \right)^{5/3}.$$

should be

$$D^K(r) = 6.88 \left(\frac{r}{r_0} \right)^{5/3}.$$

p. 160, Eq. (9.45):

$$D^{vK}(|\Delta \mathbf{r}|) = 6.16 r_0^{-5/3} \left[\frac{3}{5} \kappa_0^{-5/3} - \frac{(r/\kappa_0/2)^{5/6}}{\Gamma(11/6)} K_{5/6}(\kappa_0 r) \right].$$

should be

$$D^{vK}(r) = 6.16 r_0^{-5/3} \left[\frac{3}{5} \kappa_0^{-5/3} - \frac{(r/\kappa_0/2)^{5/6}}{\Gamma(11/6)} K_{5/6}(\kappa_0 r) \right].$$

p. 160, Eq. (9.46):

$$D^{mvK}(|\Delta \mathbf{r}|) = 3.08 r_0^{-5/3} \times \left\{ \Gamma\left(-\frac{5}{6}\right) \kappa_m^{-5/3} \left[1 -_1 F_1 \left(-\frac{5}{6}; 1; -\frac{\kappa_m^2 r^2}{4} \right) \right] - \frac{9}{5} \kappa_0^{1/3} r^2 \right\},$$

should be

$$D^{mvK}(r) = 3.08 r_0^{-5/3} \times \left\{ \Gamma\left(-\frac{5}{6}\right) \kappa_m^{-5/3} \left[1 -_1 F_1 \left(-\frac{5}{6}; 1; -\frac{\kappa_m^2 r^2}{4} \right) \right] - \frac{9}{5} \kappa_0^{1/3} r^2 \right\},$$

p. 160, Eq. (9.47):

$$D^{mvK}\left(|\Delta\mathbf{r}|\right) \simeq 7.75 r_0^{-5/3} l_0^{-1/3} r^2 \left[\frac{1}{\left(1+2.03r^2/l_0^2\right)^{1/6}} - 0.72\left(\kappa_0 l_0\right)^{1/3}\right],$$

should be

$$D^{mvK}\left(r\right) \simeq 7.75 r_0^{-5/3} l_0^{-1/3} r^2 \left[\frac{1}{\left(1+2.03r^2/l_0^2\right)^{1/6}} - 0.72\left(\kappa_0 l_0\right)^{1/3}\right],$$

p. 165, second line above Eq. (9.75): $\alpha_i = z_i/\Delta z_i$ should be $\alpha_i = z_i/\Delta z$

p. 169, third line: "Line 7" should be "Line 8"

p. 169, fourth line: "lines 9–34" should be "lines 12–37"

p. 169, third line below Eq. (9.81): "lines 15–25" should be "lines 14–26"

p. 169, third line below Eq. (9.81): "lines 27–28" should be "lines 28–29"

p. 169, fourth line below Eq. (9.81): "line 30" should be "lines 32–35"

p. 169, fifth line below Eq. (9.81): "line 32" should be "line 36"

p. 176, sixteenth line from the bottom: "line 35" should be "line 34"

p. 176, eleventh line from the bottom: "line 31" should be "line 37"

p. 182, fifth line: "line 35" should be "line 36"

p. 182, seventh: "line 37" should be "line 39"

Listing 4.2 MATLAB example of simulating a Fraunhofer diffraction pattern with comparison to the analytic result.

```
% example_fraunhofer_circ.m

N = 512;     % number of grid points per side
L = 7.5e-3;    % total size of the grid [m]
d1 = L / N;   % source-plane grid spacing [m]
D = 1e-3;    % diameter of the aperture [m]
wvl = 1e-6;   % optical wavelength [m]
k = 2*pi / wvl;
Dz = 20;      % propagation distance [m]

[x1 y1] = meshgrid((-N/2 : N/2-1) * d1);
Uin = circ(x1, y1, D);
[Uout x2 y2] = fraunhofer_prop(Uin, wvl, d1, Dz);

% analytic result
Uout_th = exp(i*k/(2*Dz)*(x2.^2+y2.^2)) ...
    / (i*wvl*Dz) * D^2*pi/4 ...
    .* jinc(D*sqrt(x2.^2+y2.^2)/(wvl*Dz));
```

to a distant observation plane. The $y_2 = 0$ slice of the resulting field's irradiance is shown in Fig. 4.1. The numerical results shown in Fig. 4.1 closely match the analytic results. However, if a large region was shown, the edges would begin to show some discrepancy. This is due to aliasing, as discussed in Sec. 2.3. If the example code was modeling a real system with a target board sensor that was only 0.4 m in diameter, then aliasing would not significantly affect the comparison between the numerical prediction and the experimentally measured diffraction pattern. The chosen grid spacing and number of grid points would be sufficient for that purpose.

To state this more concretely, the geometry of the propagation imposes a limit on the observable spatial frequency content of the source. The observation-plane coordinates are related to the spatial frequency of the source via

$$x_2 = \lambda \Delta z f_{x1} \tag{4.4a}$$

$$y_2 = \lambda \Delta z f_{y1}. \tag{4.4b}$$

Then, if a sensor in the $x_2 - y_2$ plane is 0.4 m wide, the maximum values of the observation-plane coordinates are $x_{max} = 0.2$ m and $y_{max} = 0.2$ m. This leads to maximum observable values of the source's spatial frequency $f_{x1,max}$ and $f_{y1,max}$ given by

$$f_{x1,max} = \frac{x_{2,max}}{\lambda \Delta z} \tag{4.5a}$$

$$f_{y1,max} = \frac{y_{2,max}}{\lambda \Delta z}. \tag{4.5b}$$

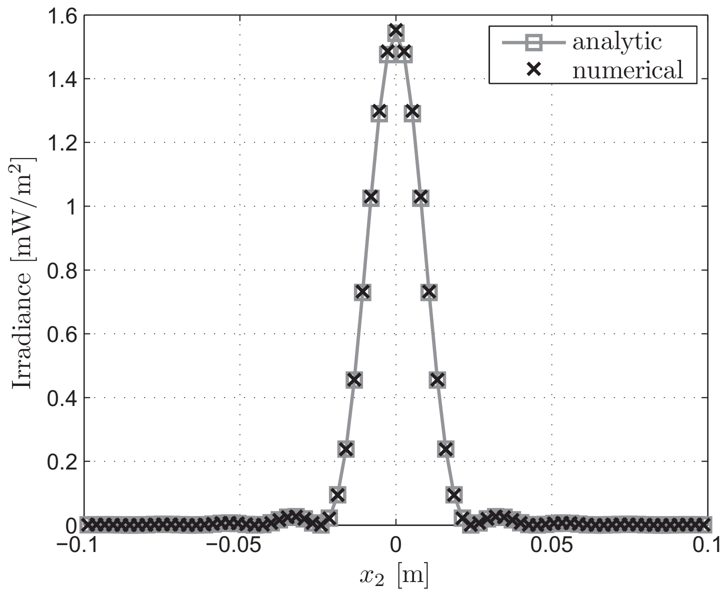

Figure 4.1 The $y_2 = 0$ slice of the irradiance of the Fraunhofer diffraction pattern for a circular aperture. Both the numerical and analytic results are shown for comparison.

As a result, in simulation, propagating a bandlimited (or filtered) version of the real source with spatial frequencies $\leq f_{x1,max}$ and $f_{y1,max}$ would produce the same observation-plane diffraction pattern as one would observe in a laboratory. This principle is used extensively in Ch. 7.

4.2 Fourier-Transforming Properties of Lenses

In this section, the discussion moves to near-field diffraction, governed by the Fresnel diffraction integral in the paraxial approximation for monochromatic waves. This is given in Eq. (1.57) and repeated here for reference:

$$U(x_2, y_2) = \frac{e^{ik\Delta z}}{i\lambda\Delta z} e^{i\frac{k}{2\Delta z}\left(x_2^2+y_2^2\right)} \int\limits_{-\infty}^{\infty}\int\limits_{-\infty}^{\infty} U(x_1, y_1) \times e^{i\frac{k}{2\Delta z}\left(x_1^2+y_1^2\right)} e^{-i\frac{2\pi}{\lambda\Delta z}(x_2x_1+y_2y_1)}\, dx_1\, dy_1. \tag{4.6}$$

Applying the Fraunhofer approximation in Eq. (4.2) removes the quadratic phase exponential in Eq. (4.6), resulting in the Fraunhofer diffraction integral. However, this approximation is not valid for the scenarios discussed in this section.

In the paraxial approximation, the phase delay imparted by a perfect, spherical (in the paraxial sense), thin lens is given by[5]

$$\phi(x, y) = -\frac{k}{2f_l}\left(x^2 + y^2\right), \tag{4.7}$$