

## Errata for *Robot Vision*

This is a list of known nontrivial bugs in *Robot Vision* (1986) by B.K.P. Horn, MIT Press, Cambridge, MA ISBN 0-262-08159-8 and McGraw-Hill, New York, NY ISBN 0-07-030349-5. Thanks go to those who found some of these problem areas in the book. — in particular Liang Wang (who translated the book into Chinese). If you know of any other problems, please advise the author by sending electronic mail to:

bkph@csail.mit.edu

Your help will be greatly appreciated. Thank you.

- Section 2.2, caption on Fig. 2–3, page 23, as well as text top of page 24 “...power emitted per unit area...” should be “...power emitted per unit foreshortened area...” (as stated correctly at the bottom of page 23).
- Section 2.3, page 25. The expression for the diameter of the blur circle should be

$$\frac{d}{z'} |\bar{z}' - z'|,$$

- Section 3.2, bottom of page 48 and top of page 49, interchange “x-axis” and “y-axis” in the text.
- Section 3.2, page 49, figure 3-2: The circled “X” is not at the centroid—it should be further to the left and higher.
- Section 3.3, page 55, the formulae for the second moments in the middle of the page are missing the term  $b(x, y)$  in the integrands:

$$\iint_I x^2 b(x, y) dx dy = \int x^2 v(x) dx \quad \& \quad \iint_I y^2 b(x, y) dx dy = \int y^2 h(y) dy.$$

- Section 6.1, page 104, near end of paragraph, after the sentence: “The transformation from the ideal image to that in the out-of-focus system is said to be a linear shift-invariant operation” add “(If we ignore the slight change in scale and overall brightness resulting from the change in the distance from the lens to the image plane).”
- Section 6.8, page 122: The equation below the middle of page should be:

$$L_\sigma(x, y) = \left( \frac{x^2 + y^2 - 2\sigma^2}{2\pi\sigma^6} \right) e^{-\frac{1}{2} \frac{x^2 + y^2}{\sigma^2}}.$$

The second sentence after this should read: “It has a central depression of magnitude  $1/(\pi\sigma^4)$  and radius  $\sqrt{2}\sigma$  surrounded by a circular wall of maximum height  $e^{-2}/(\pi\sigma^4)$  and radius  $2\sigma$ .”

- Section 6.9, page 125 after the last equation on the page it should say: "... and then drops smoothly to zero at  $rB = 3.83171 \dots$ "
- Section 6.13, top of page 134: The integrand containing  $\phi_{id}(\xi, \eta)$  has a spurious extra right parenthesis.
- Section 6.13, top of page 134: The integral for  $\phi_{dd}(0, 0)$  is missing a  $dx dy$ .
- Section 6.13, middle of page 136: The expression for  $\Phi_{id}$  should be

$$\Phi_{id} = H^* \Phi_{bb} + \Phi_{nb}$$

and the expression for  $\Phi_{ii}$  should be

$$\Phi_{ii} = H^* H \Phi_{bb} + H \Phi_{nb} + H^* \Phi_{bn} + \Phi_{nn}$$

As a result, the expression of the MTF of the optimal filter should read:

$$H' = \frac{\Phi_{id}}{\Phi_{ii}} = \frac{H^* \Phi_{bb}}{H^* H \Phi_{bb} + \Phi_{nn}}.$$

- Section 6.14, top of page 128: The expression should be (missing  $\pi$ ):

$$\bar{F}(\rho) = 2\pi R^2 \frac{J_1(\rho R)}{\rho R}$$

- Section 7.1, just above middle of page 146: The first integral should contain  $\tilde{F}(u, v)$ , not  $F(u, v)$  and  $du dv$  instead of  $dx dy$ :

$$\tilde{f}(x, y) = \frac{1}{4\pi^2} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \tilde{F}(u, v) e^{+i(ux+vy)} du dv$$

- Section 7.1, just above middle of page 146: The second integral for  $\tilde{f}(x, y)$  should contain  $du dv$  instead of  $dx dy$ .
- Section 7.2, near bottom of page 147: The integral for  $\tilde{f}(x, y)$  should contain  $du dv$  instead of  $dx dy$ .
- Section 7.2, page 148. At the end of the section it should say something like: "... so that the Fourier transform of  $f(x, y)$  times  $g(x, y)$  equals

$$\sum_{k=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} F\left(u - \frac{2\pi k}{w}, v - \frac{2\pi l}{h}\right),$$

a periodic superposition of copies of  $F(u, v)$ . It should be clear that  $F(u, v)$ , the Fourier transform of  $f(x, y)$ , can be recovered from this sum if  $F(u, v)$  is zero for  $|u| > \pi/w$  and for  $|v| > \pi/h$ , while  $F(u, v)$  cannot be recovered uniquely when this condition is not satisfied."

- Section 7.4, page 151, the sum for  $F_{mn}$  should read:

$$F_{mn} = \sum_{k=0}^{M-1} \sum_{l=0}^{N-1} f_{kl} e^{-2\pi i(\frac{km}{M} + \frac{ln}{N})}.$$

and the sum for  $f_{kl}$  should read:

$$f_{kl} = \frac{1}{MN} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} F_{mn} e^{+2\pi i (\frac{km}{M} + \frac{ln}{N})}.$$

- Section 7.4, page 153, in two places: as above, the complex exponent needs a factor of 2.
- Section 7.8, page 155, problem 7-2: the formula given is for  $g_{i,j}$ , not  $f_{i,j}$ .
- Section 8.3, top of page 165, formula is lacking a scale factor:

$$\left(\frac{\partial E}{\partial x}\right)^2 + \left(\frac{\partial E}{\partial y}\right)^2 \approx \frac{1}{2\epsilon^2} ((E_{i+1,j+1} - E_{i,j})^2 - (E_{i,j+1} - E_{i+1,j})^2).$$

- Section 9.10, page 201, figure 9-8: The number 44, near the lower left hand corner of the figure, and below the number 36, should be 144.
- Section 10.7, page 214: For consistency with what follows, the equation for  $E(\theta_i, \phi_i)$  should perhaps read:

$$E(\theta_i, \phi_i) = E \frac{\delta(\theta_i - \theta_s) \delta(\phi_i - \phi_s)}{\sin \theta_i},$$

although it is correct as it stands, since  $E(\theta_i, \phi_i)$  is zero except where  $\theta_i = \theta_s$ .

- Section 10.9, near top of page 219: Change formula to read:

$$L = \frac{1}{\pi} E \cos \theta_i \quad \text{for } \cos \theta_i \geq 0,$$

- Section 10.16, page 234, problem 10-3: This problem can be solved more easily if a spherical coordinate system is chosen that has the poles where the plane containing the local tangent plane intersects the horizon, rather than one with the poles at the nadir.
- Section 10.16, page 241, problem 10-17: Change second sentence in part (a) to read: "Demonstrate that the corners of this triangle lie in the directions  $\hat{\mathbf{s}}_3 \times \hat{\mathbf{s}}_1$ ,  $\hat{\mathbf{s}}_2 \times \hat{\mathbf{s}}_3$ , and  $\hat{\mathbf{s}}_1 \times \hat{\mathbf{s}}_2$ ."
- Section 11.1, below middle of page 246: The equations for  $x(\xi)$  and  $y(\xi)$  should contain  $\theta_0$  instead of  $\theta$ :

$$x(\xi) = x_0 + \xi \cos \theta_0 \quad \text{and} \quad y(\xi) = y_0 + \xi \sin \theta_0.$$

- Section 11.4, middle of page 256: the alternate solution is

$$z = z_0 - \frac{1}{2}(ax^2 + 2bxy + cy^2).$$

- Section 11-10, page 271, problem 11-7: In part (e), change the equation to

$$z(r) = z_0 \pm \frac{1}{2} \left( \sqrt{r^4 - k^2} - k \cos^{-1} \frac{k}{r^2} \right).$$

and add the phrase “when  $r_0 = \sqrt{k}$ .”

- Section 11-10, page 271, problem 11-9: In the second paragraph, change third sentence to read: “A hyperboloid of one sheet is an example of a ruled surface.”
- Section 11-10, page 275, problem 11-12: In part (b) there is a sign error—insert a minus sign before the  $\lambda$ s in the right hand sides of the equations. change the two equations to read:

$$\begin{aligned}(E(x, y) - R(p, q))R_p &= \lambda(q_{xy} - p_{yy}), \\ (E(x, y) - R(p, q))R_q &= \lambda(p_{xy} - q_{xx}).\end{aligned}$$

- Section 12.6, page 288, middle of the page: There is a  $\lambda$  missing in the correction terms. Change the iterative update equations to read:

$$\begin{aligned}u_{kl}^{n+1} &= \bar{u}_{kl}^n - \frac{\lambda}{1 + \lambda(E_x^2 + E_y^2)}(E_x \bar{u}_{kl}^n + E_y \bar{v}_{kl}^n + E_t)E_x, \\ v_{kl}^{n+1} &= \bar{v}_{kl}^n - \frac{\lambda}{1 + \lambda(E_x^2 + E_y^2)}(E_x \bar{u}_{kl}^n + E_y \bar{v}_{kl}^n + E_t)E_y.\end{aligned}$$

- Section 12.7, page 293, drop the sentence “Moreover, rotations about the optical axis increase the measure that we used for the departure from smoothness”
- Section 13.5, page 311, focal length  $f$  missing in “This is a straight line connecting the point  $f(u/w, v/w)$ , for  $s = 0$ , to  $f(a/c, b/c)$ , as  $s \rightarrow \infty$ .” after equations at top of page.
- Section 13.9, page 317, near bottom of page: Change equation to read:

$$F_d - \frac{\partial}{\partial x'} F_{d_{x'}} - \frac{\partial}{\partial y'} F_{d_{y'}} + \frac{\partial^2}{\partial^2 x'} F_{d_{x'x'}} + \frac{\partial^2}{\partial^2 y'} F_{d_{y'y'}} = 0.$$

- Section 16.6, page 374, end of second paragraph of section, change sentence to read: “In fact, the number of impulses per unit area on the Gaussian sphere approaches  $\rho$  times the inverse of the absolute value of the Gaussian curvature.”
- Section 16.13, page 397, problem 16-7: Change solution to part (b) to read:

$$R(\psi) = \frac{(ab)^2}{((a \cos \psi)^2 + (b \sin \psi)^2)^{3/2}}.$$

- Section 16.13, page 399, problem 16-9: Change equation in part (a) to read

$$\rho_{X \oplus Y}(\psi) = \rho_X(\psi) + \rho_Y(\psi).$$

- Section 17.5, page 416: There is a sign error in the sixth equation from the top. The term  $((u - u_r)y + (v - v_r)x)$  in the integrand should instead be  $((u - u_r)y - (v - v_r)x)$ .

- Section 18.10, page 437, near bottom of page, the equation after the phrase: “The norm of a quaternion is given by” should read:

$$\|\dot{\mathbf{q}}\| = \sqrt{\dot{\mathbf{q}} \cdot \dot{\mathbf{q}}} = \sqrt{q^2 + \mathbf{q} \cdot \mathbf{q}}.$$

- Section 18.10, page 437, at the bottom of the page, change equation to read:

$$\dot{\mathbf{q}} = \cos \frac{\theta}{2} + \boldsymbol{\omega} \sin \frac{\theta}{2}.$$

- Section 18.10, page 438, second sentence in second paragraph from the top, change to: “Two antipodal points on this sphere correspond to a particular rotation.”
- Section 18.21, page 450, problem 18-5, change middle equation to read:

$$(\dot{\mathbf{p}}\dot{\mathbf{q}}) \cdot (\dot{\mathbf{p}}\dot{\mathbf{q}}) = (\dot{\mathbf{p}} \cdot \dot{\mathbf{p}})(\dot{\mathbf{q}} \cdot \dot{\mathbf{q}}) = (\dot{\mathbf{q}}\dot{\mathbf{p}}) \cdot (\dot{\mathbf{q}}\dot{\mathbf{p}}).$$

shoul • Section A.1, page 454, after the law of cosines for the angles, add: “. . . and the so-called analogue formula is

$$\sin a \cos B = \cos b \sin c - \sin b \cos c \cos A.$$

- Section A.5.2, page 465, “The extrema of  $f(x, y, z) = 0$  subject to . . .” should be just “The extrema of  $f(x, y, z)$  subject to . . .”
- Section A.5.2, page 466, “We minimize  $abc + \dots$ ” should be “We maximize  $abc + \dots$ ”
- Section A.6.1, page 470, in the equation after “Using integration by parts, we see that” there is a prime missing on the  $F_{f'}$  in the last integrand

$$\int_{x_1}^{x_2} \eta'(x) F_{f'} dx = [\eta(x) F_{f'}]_{x_1}^{x_2} - \int_{x_1}^{x_2} \eta(x) \frac{d}{dx} F_{f'} dx,$$

- Section A.6.2, page 473 last equation on the page should be

$$\Phi \equiv F + \sum_{i=1}^m \lambda_i(x) g_i(x, f_1, f_2, \dots, f_n, f'_1, f'_2, \dots, f'_n).$$