

List of errors

The first print of the book **Robotics: Fundamental Concepts and Analysis** (2006) contained several typing and other mistakes which may lead to confusion for the reader. All these and other minor ones have been corrected in the *second print* published in May 2008. For those readers who have a copy of the *first print*, here is a list of some of the *major* typographical errors and mistakes in the text, formulas and figures.

- Equation (2.16) on page 29, the (2, 2) in the matrix has a sign mistake. The term “ $-s_1c_2s_3 - c_1c_3$ ” *should* be “ $-s_1c_2s_3 + c_1c_3$ ”.
- Page 35, third line from bottom – “(see Section 2.9....)” *should* be “(see Section 2.8....)”.
- Line below equation (2.38) – part of the statement “and that the four-dimensional ... is an eigenvector of $\frac{A}{B}[T]$.” is *incorrect*. This has been deleted in the second print.
- First line of equation (2.49) on page 48 *should* read as

$${}^i{}^{-1}[R] = [R(\hat{\mathbf{X}}_{i-1}, \alpha_{i-1})] \quad [R(\hat{\mathbf{Z}}_i, \theta_i)]$$

square brackets and “ , ” are missing.

- In Example 2.5, the coordinate systems $\{L_i\}$, $i = 1, 1, 2, 3$ are not defined or shown in figure 2.22. The coordinate systems $\{L_i\}$, $i = 1, 2, 3$ are attached to the three rotary joints R_i , $i = 1, 2, 3$ at the base of the parallel manipulator. Hence, a line has been *added* below the table on page 56 – “It may be noted that $\{L_1\}$, $\{L_2\}$, and $\{L_3\}$ are coordinate systems attached to the three rotary joints R_1 , R_2 , and R_3 , respectively.”
- In figure 2.23 on page 58, the symbol “ 1 ” near the arrowhead denoting the axis of θ_3 rotation should be removed.
- In Exercise 2.1, the symbols “ ${}^A\mathbf{P}_1$, ${}^A\mathbf{P}_2$, and ${}^A\mathbf{P}_3$ ” *should* be “ ${}^A\mathbf{p}_1$, ${}^A\mathbf{p}_2$, and ${}^A\mathbf{p}_3$ ”. The uppercase ${}^A\mathbf{P}$ denotes 4×1 vector.
- In Exercise problems 2.3 and 2.11, it is easier to visualize the orientations and estimate by using any 3D CAD software. It may be noted that the opposite faces of a dice add upto 7.
- In Exercise problem 2.15 – The arrangement of first three joints is similar to a PUMA 560.
- Page 68, the reference by Sangamesh D. R. is now available as

R. Sangamesh Deepak and A. Ghosal 2006, “A note on the diagonalizability and the Jordan form of the 4×4 homogeneous transformation matrix”, *Trans. of ASME, Jou. of Mechanical Design*, Vol. 128, No. 6, pp. 1343-1348.

- Second line from bottom, page 73 – “ 1. $n = 6$ or $n < 3$ for a ...” should read as “ 1. $n = 6$ or $n = 3$ for a ...”
- Figure 3.3, page 76 – $\hat{\mathbf{Y}}_A$ *should* read as $\hat{\mathbf{Y}}_0$.

- Page 76, first line of Example 3.5 – “... shown in Figs 2.17 and 2.18,...” *should* read as “.. shown in Figs 2.18 and 2.19,...”.

- Page 78, in the Algorithm $r_{ij} \Rightarrow \theta_4, \theta_5$ and θ_6 , the values of θ_5 are *incorrect*. It should read as:

$$\theta_5 = 0, \quad \text{and} \quad \theta_5 = \pi$$

- Page 79, equation after equation (3.23), the subscript K_4 *should* read as K_3 .

- Page 83, the superscript on the first rotation matrix is *incorrect*. Equation (3.26) should read as

$${}^3[R] = {}^0[R] {}^T_6 [R]$$

- Page 84, (3, 1) is incorrect. θ_4 is obtained as

$$\theta_4 = \text{Atan2}((3, 3)/s_5, -(1, 3)/s_5)$$

- Page 85, two lines below equation (3.29) – “[see Eqn 2.7...” should read as “[see Eqn (2.5.1)]...”.

- Page 85, last paragraph – the line “...first matrix $({}^{i-1}[T])_{jt}$..” should read as “...first matrix $({}^{i-1}[T])_{st}$..”.

- Page 86, two lines below equation (3.32) should read as “...the remaining five variables, $\theta_1, \theta_2, \theta_3, \theta_4$, and θ_5 in ...”

- Page 88, third line from bottom – “manipulator (Example 3.1, the ...” should read as “manipulator (Example 3.3, the ...”

- Figure 3.5, the heading “Joint 2 restricted120°” should be deleted. The figure is redrawn in the reprint.

- Page 93, line 7 from top *should* read as “ $\pm(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}})$ ” instead of “ $\pm(\frac{1}{2}, \frac{1}{2})$ ”.

- Page 94, in equation (3.46) a_0 and b_0 , in general, can be a function of y . Hence, “ a_0 ” and “ b_0 ” is to be replaced by “ $a_0(y)$ ” and “ $b_0(y)$ ”, respectively.

- Page 95, equation (3.51) *should* read as

$$(a_{m-1}b_n - a_m b_{n-1})x^{m-1} + (a_{m-2}b_n - a_m b_{n-2})x^{m-2} + \dots + a_0 b_n = 0$$

- Page 99, Exercise 3.13 – “....compare with Exercise 3.11.” should read as “....compare with Exercise 3.12.”.

- Page 105, in Fig. 4.1, the symbol “ θ_2 ” is to be replaced by “ ϕ_2 ”.

- Page 106, sixth line from top – the sentence “...can have 12 different loops...” is misleading as there can be more than 12 loops. It is to be *replaced by* “....can have many different loops – for example, five”.

- Page 109, equation (4.9) – the last equation *should read as*

$$\theta_1 + \phi_2 = \phi_1 + \phi_3 + \pi$$

- Page 109, equation (4.10) – the superscript T is missing.
- Page 111, seventh line from top – “dialectic” should be spelt as “dialytic”.
- Page 113, line 7 from top – “from Eqns (4.15) and (4.23)..” should read as “from Eqns (4.21) and (4.23)....”.
- Page 114, Example 4.2 – It should be “(see Fig. 2.22).”
- Page 114, the last equation in (4.25) *should read as*

$$({}^{Base}\mathbf{S}_3 - {}^{Base}\mathbf{S}_1) \cdot ({}^{Base}\mathbf{S}_3 - {}^{Base}\mathbf{S}_1) = k_{31}^2$$

- Page 115, the *last three lines should read as*
 “... constants. The second equation in Eqn (4.26) also yields a *quadratic* in x_2 with the coefficients as functions of θ_3, l_2, l_3 and constants. Following Sylvester’s dialytic method, we can eliminate θ_2 between the quartic and the quadratic...”
- Page 116, a bracket (is missing in first equation in Eqn (4.31). It should read as

$$q_8 = (p_0a^4 + p_1a^3 + p_2a^2 + p_3a + p_4)^2 \times (p_0a^4 - p_1a^3 + p_2a^2 - p_3a + p_4)^2$$

- Page 120, in equation (4.40) the symbol “ \times ” should be replaced by “ $+$ ”.
- Page 126, line after equation (4.54) should read as
 “and again using Eqns (4.51) and (4.51),...” should be “and again using Eqns (4.51) and (4.54),...”.
- Page 126, line 4 after equation (4.54) – “ p, p ” should read as “ p, q ”.
- Page 128, Equation (4.56) *should read as*

$$\phi = \theta_1 + \phi_2 - 2\pi$$

and *likewise* the term $\theta_1 + \phi_2$ in 2 lines below equation (4.58) should read as $\theta_1 + \phi_2 - 2\pi$. This follows from how the angles are marked in Fig. 4.8.

- Page 129, Example 4.6 – “in Fig. 2.22...” should read as “in Fig. 2.23...”.
- Page 129, equation (4.60) *should be corrected to*

$${}^{Base}\mathbf{S}_1 = {}^{Base}_{Object}[R]^{Object}\mathbf{S}_1 + {}^{Base}\mathbf{p}_{Object}$$

The last term was left out.

- Page 132, figure 4.10 for exercise 4.2 – The angle ϕ_3 and ϕ_2 are the angles between “Link 2 and Link 3” and between “Link 3 and Link 4” respectively. These are *not marked in the figure*. In addition, the symbol “ O_fR ” should be “ O_R ”.

- Page 134, Fig. 4.13 – “Moving platform” should read as “Moving platform”.
- In Section 5.2, the development of angular velocity matrix is discussed starting from $[R][R]^{-1}$. It is more correct and conventional to use $[R][R]^T$ and then take derivatives etc. Hence, in all equations involving angular velocity in Chapter 5 wherever $[R]^{-1}$ occurs it is to be replaced by $[R]^T$.

- Page 142, equation (5.13), the subscript 0 should be superscript 0. The equation should read as

$${}^0\mathbf{V}_p = {}^0_i[\dot{R}] {}^0_i[R]^T {}^0\mathbf{p}$$

- Page 144, line below equation (5.25) should read as
“Equations (5.21), (5.24) and (5.25) can be used to obtain,....”
- item Page 144, one line below Example 5.1 – “Figure 2.16..” should read as “Figure 2.17...”.
- Page 144, last line – “(5.25), we have” should read “(5.24, we have”.
- Page 145, two lines below equations – “...as shown in Fig. 2.16.” should read as “...as shown in Fig. 2.17”.
- Page 151, equation (5.36) *should read as*

$$g_{11} = g_{22} \quad \text{and} \quad g_{12} = 0$$

- Page 152, two lines from bottom – “Example 4.1” should read as “Example 4.2”.
- Not to confuse the symbol “ $[\mathbf{K}^*]$ ” used in Chapter 5 with the symbol used in Chapter 10, all “ $[\mathbf{K}^*]$ ” in Chapter 5 is *replaced* with light face symbol “ $[K^*]$ ”. See also Exercise problems 5.8, 5.9, 5.13. *Likewise* in some places the symbol used for the Jacobian matrix is incorrectly bold. It should be uniformly light face J
- Page 156, 4 lines below equation (5.53) – “...given in Eqn (4.32).” should read as “...given in Eqn (4.33).”
- Page 159, line below Fig. 5.6 – “From Eqn (5.53)...” should read as “From Eqn (5.55)...”.
- Page 162, 2 lines below equation (5.60) – “...equation in Eqn (4.2)...” should read as “...equation in Eqn (4.3...)”.
- Page 163, the expression for $\cos \theta_1$ above figure 5.8 should be

$$\cos \theta_1 = \frac{l_0^2 + l_1^2 - (l_2 + l_3)^2}{2l_0l_1}$$

- Page 172, “ = ” symbol is missing between the second and the third term. The equation (5.75) should read as

$${}^{B_0}\mathcal{F}_{Tool} \triangleq \begin{pmatrix} {}^{B_0}\mathbf{F}_{Tool} \\ - - - \\ {}^{B_0}\mathbf{M}_{Tool} \end{pmatrix} = \begin{bmatrix} \sum_{i=1}^6 {}^{B_0}\mathbf{s}_i f_i \\ - - - \\ \sum_{i=1}^6 ({}^{B_0}\mathbf{b}_i \times {}^{B_0}\mathbf{s}_i) f_i \end{bmatrix}$$

- Page 173, in equation (5.78), the second “ $B_0\mathbf{s}_1$ ” should be “ $B_0\mathbf{s}_2$ ”.
- Page 178, equation (5.88) – the superscript “ -1 ” should be *deleted*. It should read as

$${}^0\mathcal{V}_{Tool} = {}^0_{Tool}[J(\Theta)]\dot{\Theta}$$

- Page 179, Exercise 5.1 – “....angular velocity would be but to use?” should read s “.....angular velocity would be *put* to use?”.
- Page 179, 180, Exercise problems 5.9 and 5.14 – “...discussed in Example 5.2” should read as “...discussed in Example 5.3”
- Page 187, Equation (6.5) – The rotation matrix *should be* ${}^0_i[R]$ *instead of* ${}^i_0[R]$.
- Page 190, Equation (6.19) – The symbol “ $-$ ” is over \mathcal{L} and not over \mathbf{q} . The left-hand side of equation (6.19) should read as $\bar{\mathcal{L}}(\mathbf{q}, \dot{\mathbf{q}})$
- Page 190, Equation (6.22) – The derivative symbol “ $\dot{}$ ” should be over Ψ and *not* over \mathbf{q} .
- Page 192, Equation (6.30) – The mass matrix should have a bold \mathbf{M} .
- Page 202, Equation (6.36) – The Jacobian matrix is a light face J . The derivative symbol “ $\dot{}$ ” is over J and *not* over \mathbf{q} .
- Page 205, Equations (6.37) and (6.38) – The symbol “ M ” in the mass matrix should be bold “ \mathbf{M} ”.
- Page 211, Equation (6.45) – The last term is ${}^0\boldsymbol{\omega}_i \times ({}^0\boldsymbol{\omega}_i \times {}^0_i[R]^i\mathbf{p})$
- Page 211, line below equation (6.45) – The line *should read as* “If ${}^i\mathbf{p}$ is a constant, then ${}^i\mathbf{V}_p = {}^i\dot{\mathbf{V}}_p = 0$ and”.
- Page 212, first line of the algorithm – “...in Section 5.2...” should read as “...in Section 5.3...”.
- Page 225, line below equation (7.11) – $\theta_i u$ should read as $\theta_i(u)$.
- Page 230, equation (7.17) – The term $(x(t) - x_0)$ should read as $(x(t) - x_f)$. **This error is there in the second print also!**
- Page 231, equation (7.19) – The third equation should read as

$$a_2 = \frac{3}{t_f^2}(x_f - x_0) - \frac{2}{t_f}\dot{x}_0 - \frac{1}{t_f}\dot{x}_f$$

- Page 232, equations (7.23) should read as

$$\begin{aligned} x(t) &= a + r \cos(\phi(t)) \\ y(t) &= b + r \sin(\phi(t)) \\ z(t) &= c \end{aligned}$$

- Page 233, step 2 – 2 should be a superscript as in \mathcal{C}^2 .
- Page 243, Fig. 8.3 – The input to the top right block diagram is $T_d(s)$ and not $V_a(s)$.
- Page 246, Fig. 8.4 – The input should be $\Omega_d(s)$ and not $\Omega_d(t)$
- Page 247, equation (8.18) – the last term should read as

$$\frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

- Page 256, line 1 – “Eqn (6.14)” should read as “Eqn (6.30)”.
- Page 260, line 4 – “... θ_i ($i = 1$)...” should read as “... θ_i ($i = 1, 2$)..”
- Page 268, Equation after equation (8.42) – The second term is $\ddot{\Theta}_d$.
- Page 268, second last line – θ_{1d}^* should be replaced by θ_{id}^* .
- Page 274, equation (8.52) – The term $\ddot{\phi}$ is to be replaced with $\ddot{\phi}_d$.
- Page 278, figure 8.29 – There should be no arrow *into* the model based block with Coriolis, centripetal and gravity term.
- Page 283, two lines above Section 8.8.2 – “Section 8.7” should be Section “8.6”.
- Page 285, figure 8.32 – At the top, it should be f_x, f_y, n_z . f_x is *repeated*.
- Section 8.9 - In the text $[S]'$ should be replaced by $[S']$ as in figure 8.34.
- Page 299, Exercise 8.7 – In inequality in the third line should read as $\pi/2 \leq \phi \leq \pi$.
- Page 306, last but one block – The denominator is J_l and not J_1 .
- Page 313, 5 lines below figure 9.5 – l_t should be $l(t)$.
- Page 317, Equation (9.22) – One extra = is to be removed.
- Page 344, third line after equation (9.92) – The symbol $\dot{\mathcal{X}}$ should be $\dot{\mathcal{X}}_d$.
- Page 345, Equation (9.93) *should read as*

$$\mathbf{G}_r(\mathbf{q}_r, \mathbf{q}_f) = -[J_{\mathbf{q}_r}^T]^T [K_p]_{\mathcal{X}} \delta \mathcal{X} + \mathbf{G}_r(\mathbf{q}_{r_d}, \mathbf{q}_{f_d})$$

- Page 359, The reference “Chandra Shaker, M.” is now available as
Chandra Shaker, M. and A. Ghosal 2006, “Nonlinear modeling of flexible manipulators using non-dimensional variables”, *ASME Trans., Jou. of Nonlinear and Computational Dynamics*, Vol. 1, pp. 123-134.
- Page 370, Figure 10.3 – The plot and the axis numbers are to be shifted up and to the right.
- Page 396 – In equation (10.36) and line below, the symbol Ψ should be bold face as $\mathbf{\Psi}$.

- Page 406, three lines below figure 10.30, the expression should read as

$$(u_g, v_g, a_0 \cos(\omega_1 u_g) \sin(\omega_2 v_g))$$

I wish to thank the readers who have pointed out many of the mistakes. Pointing out any additional mistakes would be *highly* appreciated.