FUNDAMENTALS OF ROBOTIC MECHANICAL SYSTEMS

Fourth Edition

Theory, Methods, and Algorithms

Errata

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Introduction: In order to ease the finding of items in this document, we have kept the page format and the original fonts of the book; we have also typeset with typewriter font---the one used in this Introduction---text that does not belong to the book.

p. 93: The correct matrix $[\mathbf{R}_2]_{\mathcal{C}}$ is

$$[\mathbf{R}_2]_{\mathcal{C}} = \begin{bmatrix} 0.373 & -0.926 & 0.043 \\ 0.902 & 0.352 & -0.249 \\ 0.215 & 0.132 & 0.967 \end{bmatrix}$$

p. 129: Line below Eq. (3.133a): in light of Eq. (2.39), should read: in light of Eq. (2.40)

p. 137: In Exercise 3.20, the expression for $\mathbf{M}_A$ is faulty. The correct expression is

$$\mathbf{M}_A = \mathbf{M}_C + m\mathbf{P}\mathbf{P}^T$$

p. 144: The last line of text, "One thus has, using subscripted brackets as introduced in Sect. 2.2,", should read:

"One thus has, using subscripted brackets as introduced in Sect. 2.3,"

p. 171: The third line of text below eq. (4.33), "From Definition 2.2.1, then $[u]1 = [e7]1 = [e6]1$", should read:

"From Definition 2.2.1, then $[\mathbf{u}]_1 = [\mathbf{e}_7]_1 = [\mathbf{e}_6]_1$"

p. 176: In the last line, the value of θ_3 is wrong. It should read:

$$\theta_3 = -\frac{\pi}{2}$$

p. 178: The correct expression for $\mathbf{Q}_{123}$ is

$$\mathbf{Q}_{123} = \mathbf{Q}_1\mathbf{Q}_2\mathbf{Q}_3 = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$[\mathbf{e}_6]_4$ should read:

$$[\mathbf{e}_6]_4 = (\mathbf{Q}_1\mathbf{Q}_2\mathbf{Q}_3)^T[\mathbf{e}_6]_1 = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 2/3 \\ -2/3 \\ -1/3 \end{bmatrix} = \begin{bmatrix} 2/3 \\ 2/3 \\ -1/3 \end{bmatrix}$$

$\theta_{4,2}$ should be

$$\theta_{4,2} = -80.26438967^\circ$$

p. 182: The caption of Fig. 4.26 is faulty. The correct caption is

Motoman-EA1400N welding robot: (a) top view; (b) side view; (c) orthographic projection; (d) **view A**, as per side view; (e) **view B**, as per side view. All dimensions in mm

p. 200: Where it reads: (b) the moments of the three lines about any point on the intersecting line are all zero, the correct wording should read:

(b) the moments of the three lines with respect to the intersecting line are all zero.

p. 202: The expression for α is faulty. The correct expression is

$$\alpha = \frac{\sqrt{a_3^2 + b_4^2}}{\sqrt{a_2^2 + d^2} + \sqrt{a_3^2 + b_4^2}}$$

Please refer to Appendix A for details.

p. 211: Where it reads: with $\boldsymbol{\tau}_a$ and $\boldsymbol{\tau}_w$ defined as the wrist and the arm torques, respectively, the correct wording should read:

with $\boldsymbol{\tau}_a$ and $\boldsymbol{\tau}_w$ defined as the arm and the wrist torques, respectively.

p. 219: Equation (5.67c) should read:

$$\ddot{\theta}_1 = \ddot{\phi} - (\ddot{\theta}_2 + \ddot{\theta}_3)$$

p. 287: In eq.(7.19a) the correct expression for the right-hand side is

$$= \boldsymbol{\phi}_n - -- > \boldsymbol{\phi}_{\bar{p}}$$

p. 288: In eq.(7.20) the correct expression for the right-hand side is

$$= \boldsymbol{\phi}_n - - - > \boldsymbol{\phi}_{\bar{p}}$$

p. 291: The second line of the expression for ι_2 should read:

$$-\frac{1}{2} m_3 a_3 (a_1 s_{23} + 2a_2 s_3)\dot{\theta}_1\dot{\theta}_3 - m_3 a_2 a_3 s_3 \dot{\theta}_2\dot{\theta}_3 - \frac{1}{2} m_3 a_2 a_3 s_3 \dot{\theta}_3^2$$

p. 312: In text below eq.(7.64), where it reads "defined in Sect. 7.4.1" the correct phrase is "defined, in turn, in Subsection 7.4.1"

In eq.(7.66b), where it reads $i = 1, \ldots, n$ the correct range is $i = 2, \ldots, n$

p. 321: Caption of Fig. 7.7 should read:

Mass-center location of the robot of Fig. 4.17

p. 324: The second line of the expression for $\dot{\mathbf{t}}_{11}$ should read:

$$= \begin{bmatrix} \dot{\mathbf{e}}_1 \\ \dot{\mathbf{e}}_1 \times \boldsymbol{\rho}_1 + \mathbf{e}_1 \times \dot{\boldsymbol{\rho}}_1 \end{bmatrix}$$

The second line of the expression for $\dot{\mathbf{t}}_{21}$ should read:

$$= \begin{bmatrix} \mathbf{0} \\ \mathbf{e}_1 \times (\boldsymbol{\omega}_1 \times \mathbf{a}_1 + \boldsymbol{\omega}_2 \times \boldsymbol{\rho}_2) \end{bmatrix} = p \begin{bmatrix} \mathbf{0} \\ (a/2)(\mathbf{i} - 3\mathbf{j}) \end{bmatrix}$$

The fourth line of the expression for $\dot{\mathbf{t}}_{31}$ should read:

$$= p \begin{bmatrix} \mathbf{0} \\ (a/2)(\mathbf{i} - 3\mathbf{j}) \end{bmatrix}$$

The second line of the expression for $\dot{\mathbf{t}}_{32}$ should read:

$$= \begin{bmatrix} p\mathbf{e}_1 \times \mathbf{e}_2 \\ (p\mathbf{e}_1 \times \mathbf{e}_2) \times (\mathbf{a}_2 + \boldsymbol{\rho}_3) + \mathbf{e}_2 \times [p(\mathbf{e}_1 + \mathbf{e}_2) \times \mathbf{a}_2 + p(\mathbf{e}_1 + \mathbf{e}_2 + \mathbf{e}_3) \times \boldsymbol{\rho}_3] \end{bmatrix}$$

p. 325: Entry (3,1) of matrix $\mathbf{T}^T\mathbf{M}\dot{\mathbf{T}}$ is flawed. The correct expression for this matrix is:

$$\mathbf{T}^T\mathbf{M}\dot{\mathbf{T}} = p\begin{bmatrix} -(1/4)a^2m & (7/4)a^2m & -(1/2)a^2m - I \\ (1/4)a^2m & 0 & (1/4)a^2m + I \\ (3/4)a^2m & (1/4)a^2m - I & 0 \end{bmatrix} \equiv \overline{\mathbf{P}}$$

p. 326: Entries (1,3), (2,3) and (3,1) of matrix $\dot{\mathbf{I}}$ are faulty. The correct expression of the matrix is

$$\dot{\mathbf{I}} = p\begin{bmatrix} -(1/2)a^2m & (5/4)a^2m & -I + (1/4)a^2m \\ (5/4)a^2m & 0 & (1/2)a^2m \\ -I + (1/4)a^2m & (1/2)a^2m & 0 \end{bmatrix}$$

p. 327: The second-to-last line of text, "Now we have", should read:

"Now, the matrix **C** of Coriolis and centrifugal forces is obtained as shown below:"

The last equation displayed should read:

$$\mathbf{C} = \mathbf{T}^T\mathbf{M}\dot{\mathbf{T}} + \mathbf{T}^T\mathbf{W}\mathbf{M}\mathbf{T} = p\mathbf{A}$$

p. 328 Entry (1,1) of matrix **A** is flawed. The correct expression is

$$\mathbf{A} \equiv \begin{bmatrix} -(1/4)a^2m & (7/4)a^2m + I & -(1/2)a^2m - 2I \\ -(1/2)a^2m - I & 0 & (1/4)a^2m + 2I \\ (3/4)a^2m + I & (1/4)a^2m - 2I & 0 \end{bmatrix}$$

The first entry of the vector array in the second equation display has a ''(1/2)'' too much. The correct display is

$$(\mathbf{T}^T\mathbf{M}\dot{\mathbf{T}} + \mathbf{T}^T\mathbf{W}\mathbf{M}\mathbf{T})\dot{\boldsymbol{\theta}} = p^2\begin{bmatrix} a^2m - I \\ -(1/4)a^2m + I \\ a^2m - I \end{bmatrix}$$

p. 329: The second line of the expression for $\ddot{\mathbf{c}}_3$ has an "=" too much. It should read:

$$+\boldsymbol{\omega}_3 \times (\boldsymbol{\omega}_3 \times \boldsymbol{\rho}_3) = \frac{1}{2}ap^2(-4\mathbf{j} + \mathbf{k}) - \frac{1}{2}ap^2\mathbf{j} + \frac{1}{2}ap^2(2\mathbf{i} - \mathbf{j} + \mathbf{k})$$

The expressions for $\mathbf{f}_2^P$, $\mathbf{n}_2^P$ and $\mathbf{f}_1^P$ are faulty. They should read:

$$
\begin{aligned}
\mathbf{f}_2^P &= m_2\ddot{\mathbf{c}}_2 + \mathbf{f}_3^P = \frac{1}{2}amp^2(-4\mathbf{j}+\mathbf{k}) - 2amp^2\mathbf{j} = \frac{1}{2}amp^2(-8\mathbf{j}+\mathbf{k}) \\
\mathbf{n}_2^P &= \underbrace{\mathbf{I}_2\dot{\boldsymbol{\omega}}_2}_{Ip^2(-\mathbf{i})} + \underbrace{\boldsymbol{\omega}_2 \times \mathbf{I}_2\boldsymbol{\omega}_2}_{\mathbf{0}} + \underbrace{\mathbf{n}_3^P}_{Ip^2(-\mathbf{i}+\mathbf{j}-\mathbf{k})+a^2mp^2(\mathbf{i}-2\mathbf{k})} + \underbrace{(\mathbf{a}_2 - \boldsymbol{\rho}_2)\times\mathbf{f}_3^P}_{a^2mp^2(-\mathbf{i}+\mathbf{k})} \\
&\quad + \underbrace{\boldsymbol{\rho}_2 \times \mathbf{f}_2^P}_{\frac{1}{4}a^2mp^2(-6\mathbf{i}-\mathbf{j}-8\mathbf{k})} \\
&= Ip^2(-2\mathbf{i}+\mathbf{j}-\mathbf{k}) + \frac{1}{4}a^2mp^2(-6\mathbf{i}-\mathbf{j}-12\mathbf{k}) \\
\mathbf{f}_1^P &= m_1\ddot{\mathbf{c}}_1 + \mathbf{f}_2^P = \frac{1}{2}amp^2(\mathbf{i}-\mathbf{j}) + \frac{1}{2}amp^2(-8\mathbf{j}+\mathbf{k}) \\
&= \frac{1}{2}amp^2(\mathbf{i}-9\mathbf{j}+\mathbf{k})
\end{aligned}
$$

p. 330: The second equation display, that of τ_1, is faulty. The correct expression reads:

$$\tau_1 = \mathbf{n}_1^P \cdot \mathbf{e}_1 = -Ip^2 + a^2mp^2$$

The first component of vector $\mathbf{C}(\boldsymbol{\theta}, \dot{\boldsymbol{\theta}})\dot{\boldsymbol{\theta}}$ is faulty. The correct expression is

$$\mathbf{C}(\boldsymbol{\theta}, \dot{\boldsymbol{\theta}})\dot{\boldsymbol{\theta}} = \begin{bmatrix} -Ip^2 + a^2mp^2 \\ Ip^2 - (1/4)a^2mp^2 \\ -Ip^2 + a^2mp^2 \end{bmatrix}$$

Appendix A

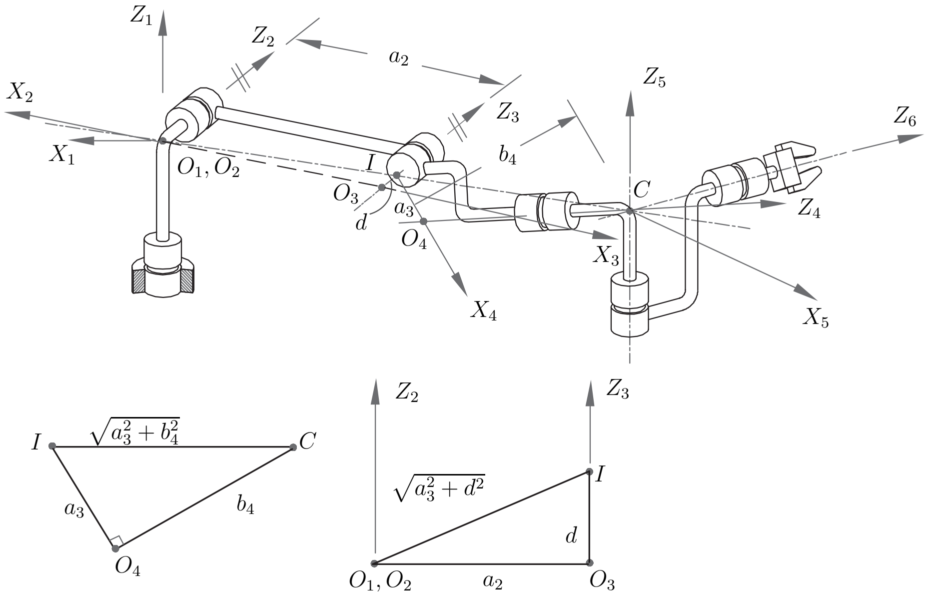

FIGURE 1. Elbow singularity of the Puma robot

With reference to the figure above, the relations below can be derived:

$$\alpha = \frac{\overline{IC}}{\overline{O_2C}}$$

$$\overline{IC} = \sqrt{a_3^2 + b_4^2}$$

$$\overline{O_2C} = \overline{O_2I} + \overline{IC}$$

$$\overline{O_2I} = \sqrt{a_2^2 + d^2}$$