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Chapter 2 Solutions for Introduction to Robotics

1. a) Use (2.3) to obtain

$${}^{A}_{B}R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix}$$

b) Use (2.74) to get

 $\begin{aligned} \alpha &= 90 \text{ degrees} \\ \beta &= 90 \text{ degrees} \\ \gamma &= -90 \text{ degrees} \end{aligned}$

2. a) Use (2.64) to obtain

$${}^{A}_{B}R = \begin{bmatrix} .330 & -.770 & .547 \\ .908 & .418 & .0396 \\ -.259 & .483 & .837 \end{bmatrix}$$

- b) Answer is the same as in (a) according to (2.71)
- 3. Use (2.19) to obtain the transformation matrices. The rotation is X-Y-Z fixed angles, so use (2.64) for that 3×3 submatrix, with angles

$$\gamma = 0 \text{ degrees}$$

$$\beta = -\sin^{-1} \left(\frac{\text{tripod_height}}{\text{distance_along_optical_axis}} \right) = -\sin^{-1} \left(\frac{1.5}{5} \right) = -107 \text{ degrees}$$

$$\alpha_C = 0 \text{ degrees}$$

$$\alpha_D = 120 \text{ degrees}$$

$$\alpha_E = 240 \text{ degrees}$$

The position vectors to the camera-frame origins are

$${}^{B}P_{CORG} = \begin{bmatrix} \text{horizontal_distance} \\ 0 \\ \text{tripod_height} \end{bmatrix} = \begin{bmatrix} 4.77 \\ 0 \\ 1.50 \end{bmatrix}$$
$${}^{B}P_{DORG} = \begin{bmatrix} \text{horizontal_distance} \times \cos \alpha_D \\ \text{horizontal_distance} \times \sin \alpha_D \\ \text{tripod_height} \end{bmatrix} = \begin{bmatrix} -2.39 \\ 4.13 \\ 1.5 \end{bmatrix}$$
$${}^{B}P_{EORG} = \begin{bmatrix} \text{horizontal_distance} \times \cos \alpha_E \\ \text{horizontal_distance} \times \sin \alpha_E \\ \text{tripod_height} \end{bmatrix} = \begin{bmatrix} -2.38 \\ -4.13 \\ 1.50 \end{bmatrix},$$

where horizontal_distance = $\sqrt{(\text{distance_along_optical_axis})^2 - (\text{tripod_height})^2}$. Combining the rotation and translation yields the transformation matrices via (2.19) as

$${}^{B}_{C}T = \begin{bmatrix} -.300 & 0 & -.954 & 4.77 \\ 0 & 1.00 & 0 & 0 \\ .954 & 0 & -.300 & 1.50 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
$${}^{B}_{D}T = \begin{bmatrix} .150 & -.866 & .477 & -2.39 \\ -.260 & -.500 & -.826 & 4.13 \\ .954 & 0 & -.300 & 1.50 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
$${}^{B}_{E}T = \begin{bmatrix} .150 & .866 & .477 & -2.39 \\ .260 & -.500 & .826 & -4.13 \\ .954 & 0 & -.300 & 1.50 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

4. The camera-frame origin is located at ${}^{B}P_{CORG} = \begin{bmatrix} 7 & -2 & 5 \end{bmatrix}^{\mathsf{T}}$. Use (2.19) to get the transformation, ${}^{B}_{C}T$. The rotation is Z-Y-X Euler angles, so use (2.71) with

 $\begin{aligned} \alpha &= 0 \text{ degrees} \\ \beta &= -110 \text{ degrees} \\ \gamma &= -20 \text{ degrees} \end{aligned}$

to get

$${}^{B}_{C}T = \begin{bmatrix} -.342 & .321 & -.883 & 7.00 \\ 0 & .940 & .342 & -2.00 \\ .940 & .117 & -.321 & 5.00 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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$${}^{B}P_{1} = {}^{B}P_{0} + 5 {}^{B}V_{0} = [9.5 \quad 1.00 \quad -1.50]^{\mathsf{T}}$$

The object's position in $\{A\}$ is

$${}^{A}P_{1} = {}^{A}_{B}T {}^{B}P_{1} = \begin{bmatrix} -4.89 & 2.11 & 3.60 \end{bmatrix}^{\mathsf{T}}$$

6. (2.1)

$$R = \operatorname{rot}(Y, \phi) \operatorname{rot}(Z, \theta)$$

$$= \begin{bmatrix} c\phi & 0 & s\phi \\ 0 & 1 & 0 \\ -s\phi & 0 & c\phi \end{bmatrix} \begin{bmatrix} c\theta & -s\theta & 0 \\ s\theta & c\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} c\phi c\theta & -c\phi s\theta & s\phi \\ s\theta & c\theta & 0 \\ -s\phi c\theta & s\phi s\theta & c\phi \end{bmatrix}$$

7. (2.2)

$$R = \operatorname{rot}(\hat{X}, 60) \operatorname{rot}(\hat{Y}, -45)$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & .500 & -.866 \\ 0 & .866 & .500 \end{bmatrix} \begin{bmatrix} .707 & 0 & -.707 \\ 0 & 1 & 0 \\ .707 & 0 & .707 \end{bmatrix}$$

$$= \begin{bmatrix} .707 & 0 & -.707 \\ -.612 & .500 & -.612 \\ .353 & .866 & .353 \end{bmatrix}$$

8. (2.12) Velocity is a "free vector" and only will be affected by rotation, and not by translation:

$${}^{A}V = {}^{A}_{B}R^{B}V = \begin{bmatrix} .707 & 0 & -.707 \\ -.612 & .500 & -.612 \\ .353 & .866 & .353 \end{bmatrix} \begin{bmatrix} 30.0 \\ 40.0 \\ 50.0 \end{bmatrix}$$
$$= \begin{bmatrix} -14.1 & -29.0 & 62.9 \end{bmatrix}^{\mathsf{T}}$$

9. (2.31)

$${}_{B}^{C}T = \begin{bmatrix} 0 & 0 & -1 & 2 \\ .500 & -.866 & 0 & 0 \\ -.866 & -.500 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

10. (2.37) Using (2.45) we get that

$${}^{B}P_{AORG} = -{}^{A}_{B}R^{\mathsf{T} A}P_{AORG} = - \begin{bmatrix} .25 & .87 & .43 \\ .43 & -.50 & .75 \\ .86 & .00 & -.50 \end{bmatrix} \begin{bmatrix} 5.0 \\ -4.0 \\ 3.0 \end{bmatrix} = \begin{bmatrix} .94 \\ -6.4 \\ -2.8 \end{bmatrix}$$

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