

# Solution

## Kinematic Chains

### Task 1. Homogeneous Transformations

- a)  $O = A1$ :  
 ${}^W\mathbf{T}_{G1} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A1} \cdot {}^O\mathbf{T}_G$
- b)  $O = A2$ :  
 ${}^W\mathbf{T}_{G2} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A1} \cdot {}^O\mathbf{T}_G$
- c)  $O = A1, G = TCP$ :  
 ${}^R\mathbf{T}_{G1} = {}^R\mathbf{T}_{TCP}$
- d)  $O = A1, G = TCP$ :  
 ${}^R\mathbf{T}_{O1} = {}^R\mathbf{T}_{G1} \cdot ({}^O\mathbf{T}_G)^{-1}$
- e)  $O = A1, G = TCP$ :  
 ${}^R\mathbf{T}_{T1} = {}^R\mathbf{T}_{O1} \cdot ({}^T\mathbf{T}_{A1})^{-1}$

### Task 2. Process in relative coordinates

- a)  ${}^W\mathbf{T}_{Z1} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A1} \cdot {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$
- b)  ${}^W\mathbf{T}_{Z2} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A2} \cdot {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$

### Task 3. Program in world coordinates

1. Move to:  ${}^W\mathbf{T}_{Z1} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A1} \cdot {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$
2. Move to:  ${}^W\mathbf{T}_{G1} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A1} \cdot {}^O\mathbf{T}_G$
3. Close Gripper
4. Move to:  ${}^W\mathbf{T}_{Z1} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A1} \cdot {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$
5. Move to:  ${}^W\mathbf{T}_{Z2} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A2} \cdot {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$
6. Move to:  ${}^W\mathbf{T}_{G2} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A2} \cdot {}^O\mathbf{T}_G$
7. Open Gripper
8. Move to:  ${}^W\mathbf{T}_{Z2} = {}^W\mathbf{T}_T \cdot {}^T\mathbf{T}_{A2} \cdot {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$

### Task 4. Program in object coordinates

1. Move to:  ${}^O\mathbf{T}_{Z1} = {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$
2. Move to:  ${}^O\mathbf{T}_{G1} = {}^O\mathbf{T}_G$
3. Close Gripper
4. Move to:  ${}^O\mathbf{T}_{Z1} = {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$
5. Move to:  ${}^O\mathbf{T}_{Z2} = \underline{DIFF} \cdot {}^O\mathbf{T}_G$  (the shifted coordinate origin was considered),  
 $\underline{DIFF} = ({}^W\mathbf{T}_{A1})^{-1} \cdot {}^W\mathbf{T}_{A2}$
6. Move to:  ${}^O\mathbf{T}_{G2} = {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, -dz)$
7. Open Gripper
8. Move to:  ${}^O\mathbf{T}_{Z2} = {}^O\mathbf{T}_G \cdot \text{trans}(0, 0, dz)$