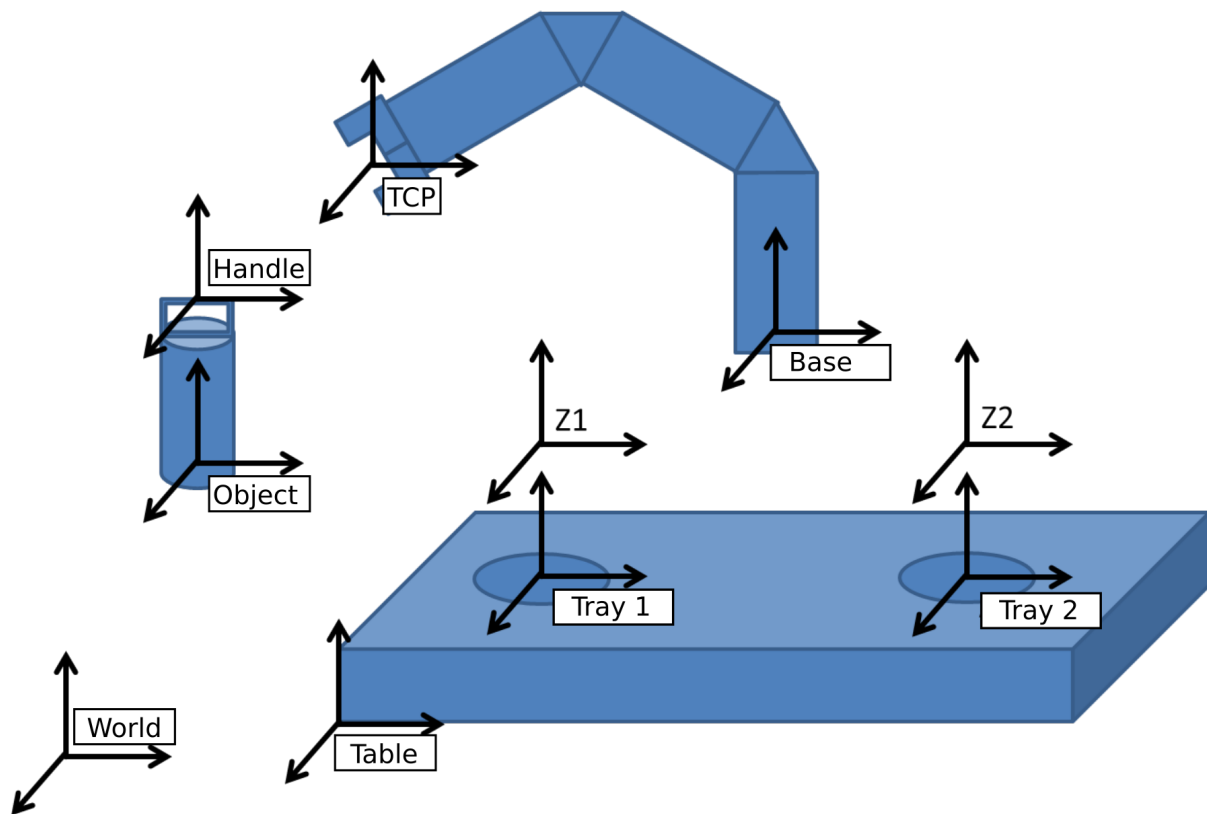


Exercise

Kinematic Chains

Pick-and-Place In this task, you are required to prepare a robot's program. Its intended purpose is to pick up an object that is initially located on *Tray 1* and place it on *Tray 2*. The object is gripped by its handle.



A program that transports the object from tray 1 to tray 2 is structured as follows:

1. Move fast and without the object to hover pose *Z1* just above the object on tray 1.
2. Move slowly and without the object to the handle of the object on tray 1.
3. Grip the object's handle.
4. Move slowly and with the object to hover pose *Z1*.
5. Move fast and with the object to hover pose *Z2* above tray 2.
6. Move slowly and with the object to tray 2.
7. Release the object's handle.
8. Move slowly and without the object to hover pose *Z2*.

Task 1. Determine the homogeneous transformations

To successfully program the robot, you need to know the respective homogeneous transformations. The following coordinate systems are known:

- World coordinates: W
- Table in world coordinates: ${}^W\underline{T}_T$
- Trays 1 and 2 in table coordinates: ${}^T\underline{T}_{A1}, {}^T\underline{T}_{A2}$
- Handle in object coordinates: ${}^O\underline{T}_G$
- Robot base in world coordinates: ${}^W\underline{T}_R$
- Robot TCP in robot base coordinates: ${}^R\underline{T}_{TCP}$

Determine the following transformations using semantics known from kinematic chains:

- a) The location of the handle in world coordinates given that the object is located on tray 1: ${}^W\underline{T}_{G1}$
- b) The location of the handle in world coordinates given that the object is located on tray 2: ${}^W\underline{T}_{G2}$
- c) The location of the handle in robot coordinates given that the object's handle is gripped while standing on tray 1: ${}^R\underline{T}_{G1}$
- d) The location of the object in robot coordinates given that the object's handle is gripped while standing on tray 1: ${}^R\underline{T}_{O1}$
- e) The location of the table in robot coordinates given that the object's handle is gripped while standing on tray 1: ${}^R\underline{T}_{T1}$

Task 2. Moving in relative coordinates

Determine the following transformations to enable the approach of the robot towards the object's handle with reduced velocity.

- a) The hover pose $Z1$ in world coordinates, which is located relative to the object's handle with a displacement of dz in the direction of the z axis: ${}^W\underline{T}_{Z1}$
- b) The hover pose $Z2$ in world coordinates, which is located relative to the object's handle with a displacement of dz in the direction of the z axis: ${}^W\underline{T}_{Z2}$

Task 3. Robot's program in world coordinates

Determine the program in world coordinates. Enumerate all coordinates the robot needs to approach in the program steps 1-8.

Task 4. Robot's program in object coordinates

As an alternative, determine the program in object coordinates. Enumerate all coordinates the robot needs to approach in the program steps 1-8.