Introduction to Cognitive Robotics

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Lecture 11

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Robot Manipulators

- Robot Programming by Task Specification
- Convention for embedding T6 and end-effector frames
- Specifying orientation
- Roll, pitch, yaw
- Euler angles

Robot Programming by Task Specification

By defining a series of manipulator end-effector positions *Mn*, a task can be described as a sequence of manipulator movements to these defined positions

For example, a task to pick and place an object might be formulated as follows

M0:	Move out of the field of view of the camera
	Determine the pose of a object and a suitable grasp point (possibly using a camera)
M1:	Move to an approach position close to the grasp point
M2:	Move to the grasp position
	Grasp the object
M3:	Move to the depart position above the grasp point
M4:	Move to the approach position in above the destination position
M5:	Move to the destination position
	Release the object
M6:	Move to the depart position away from the destination position

- We are specifying the task in terms of movements of the robot but the object are what we are really interested in

- The object movements are implicit in the fact that the manipulator has grasped it

- We make up for this when we describe the structure of the task by considering the structure of the task's component objects:

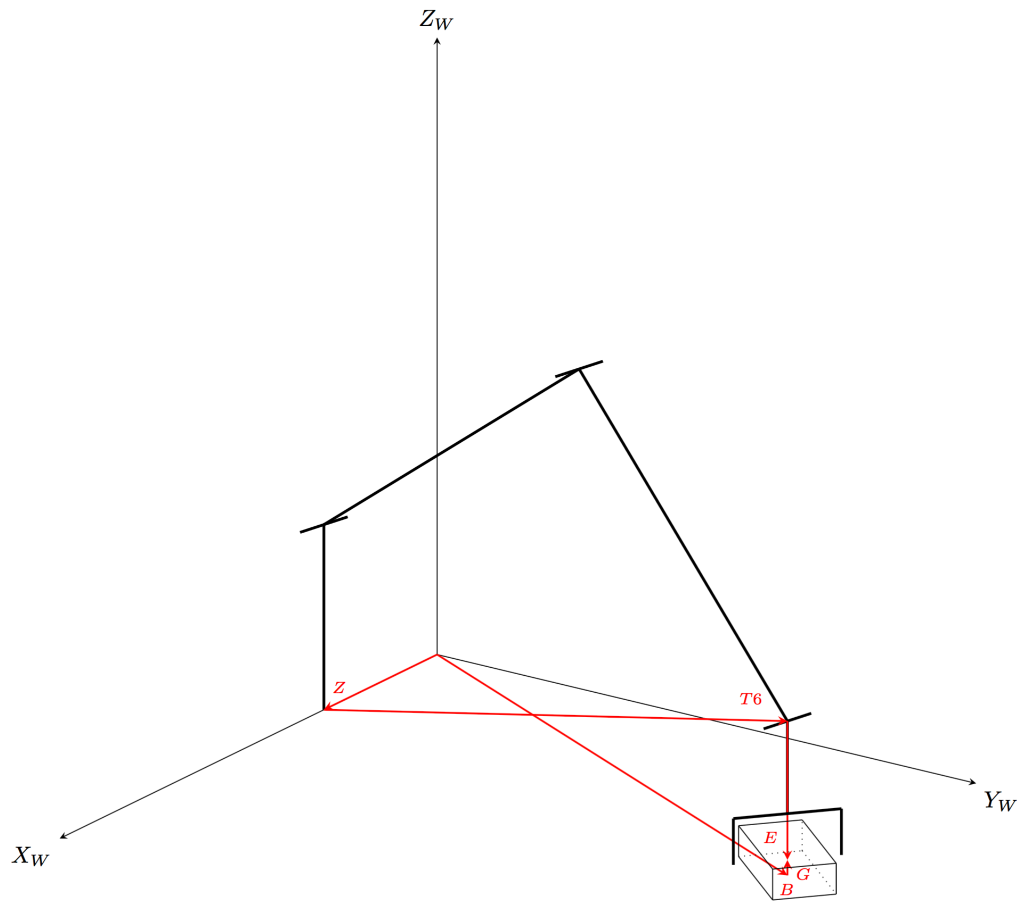
  – the manipulator
  – the end-effector
  – the object being manipulated
  – the object grasp pose

- In particular, we will use the explicit positional relationships between these objects to describe the task structure

Since coordinate frames can be used to describe object position and orientation ...

And since we may need to describe a coordinate frame in two or more ways (there is more than one way to reach any given position and orientation) ...

We use transform equations to relate the two descriptions



A manipulator grasping a block

Z is the transformation (frame) which describes the position of manipulator with respect to the base co-ordinate reference frame

${}^{Z}T6$ describes the end of the manipulator (*i.e.* the wrist) with respect to the base of manipulator, *i.e.* with respect to Z

${}^{T6}E$ describes the end-effector with respect to the end of the manipulator, *i.e.* with respect to $T6$

B describes a block's position with respect to the base coordinate reference frame

${}^{B}G$ describes the manipulator end-effector with respect to the block, ***i.e.*** with respect to B.

In this example, the end-effector is described in two ways, by the transformations leading from the base to the wrist to the end-effector :

$$Z * {}^{Z}T6 * {}^{T6}E$$

and by the transformations leading from the block to the end-effector grip position:

$$B * {}^{B}G$$

Equating these descriptions, we get the following transformation equation:

$$Z * {}^{Z}T6 * {}^{T6}E = B * {}^{B}G$$

- Solving for $T6$ by multiplying across by the inverse of Z and ${}^{T6}E$

$$ {}^{Z}T6 = Z^{-1} * B * {}^{B}G * {}^{T6}E^{-1} $$

- $T6$ is a function of the joint variables of the manipulator and, if known, then the appropriate joint variables can be computed using the inverse kinematic solution

- $T6$ then is the coordinate frame which we wish to program in order to effect the manipulation task

- An arm position and orientation specified by $T6$ is, thus, equivalent to our previous informal movement Mn

$$\text{Move } Mn = \text{Move } {}^{Z}T6$$

  – since we can compute $T6$ in terms of our known frame we now have an arm movement which is specified in terms of the frames which describe the task structure

- Assigning the appropriate value to *T6* and moving to that position, implicitly using the inverse kinematic solution

$^{Z}T6 = Z^{-1} * B * {}^{B}G * {}^{T6}E^{-1}$

Move $^{Z}T6$

- What we have not yet done is to fully specify each of these frames by embedding them in the appropriate objects and specifying the transformations which define them

- Note that the position of the end-effector with respect to the base reference system is represented by

$$Z * {}^{Z}T6 * {}^{T6}E$$

- This allows you to generate general-purpose and reusable robot programs

- In particular, the calibration of the manipulator to the workstation is represented by Z, while if the task is to be performed with a change of tool, only E need be altered.

- As we have seen, we specify the orientation of $T6$ by solving for it in terms of other frames/transformations in the task specification ...

- We do this by

1. Embedding a frame in an object (or a desired point in space)

2. Specifying the position of the origin of the frame by applying a translation

3. Specifying the orientation of the frame by applying one or more rotations

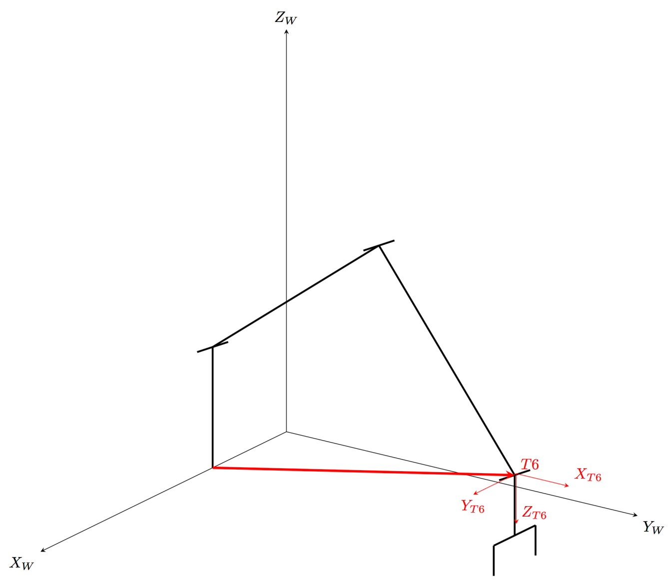
There is a convention that the $T6$ frame should be embedded in the manipulator

– with the origin at the wrist

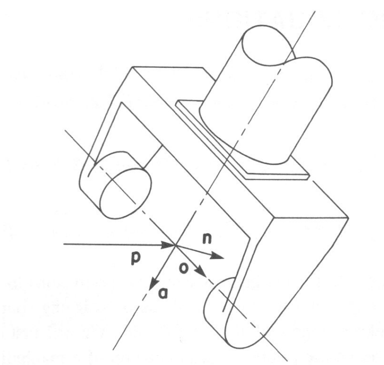
– with the Z axis directed outward from the wrist to the gripper

– with the Y axis directed in the plane of movement of the gripper when it is opening and closing

– with the X axis making up a right-hand system



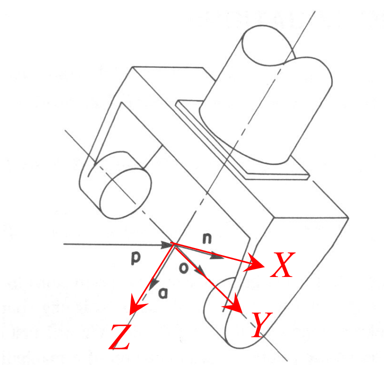
The same convention applies to the E frame that is embedded in a two-finger gripper (end-effector … hence E)



$$E = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

n Normal
o Orientation
a Approach

The same convention applies to the E frame that is embedded in a two-finger gripper (end-effector … hence E)



Direction of X axis

Direction of Y axis

Direction of Z axis

$$E = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

n Normal

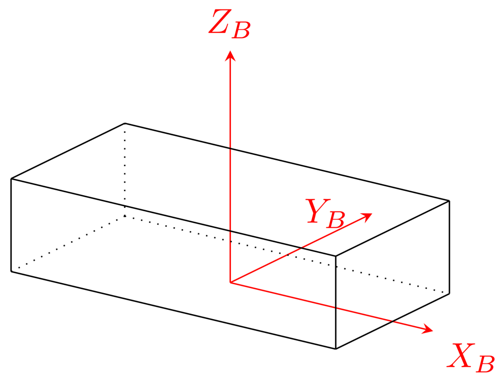
o Orientation

a Approach

Specifying Pose

We have seen that the pose of an object can be specified by embedding a frame in the object in some appropriate manner … for example:

- Placing the origin at the centre of the object
- Aligning the axes with the major and minor axes of the object

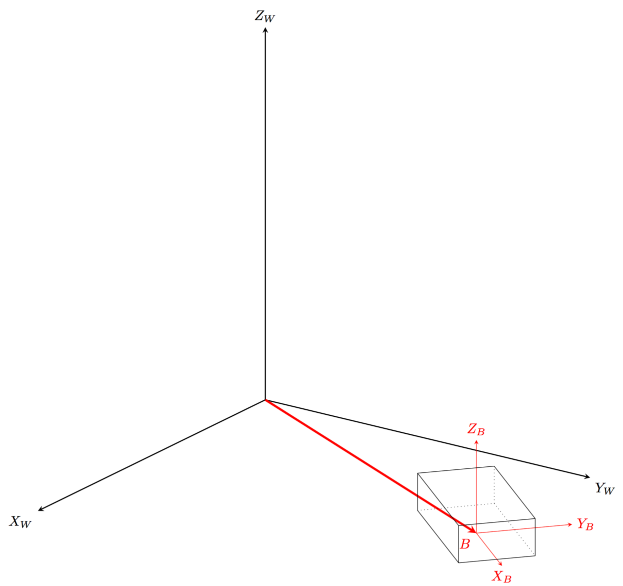


Specifying Pose

Then applying a homogenous transformation, e.g. $B = Trans\ (10, 20, 0)\ Rot\ (Z, 50)$

- Translation part
  - Possibly several translations, applied in turn
- Rotation part
  - Possibly several rotations, applied in turn

You can specify them in whatever order you like, yielding a valid transform equation such as
$B = Trans\ (10, 20, 0)\ Rot\ (Z, 50)\ Rot\ (X, 10)\ Rot\ (Z, 30)$



Specifying Orientation

That said, there are several conventions for the way these rotations are specified

One is Roll-Pitch-Yaw (RPY) … sometimes referred to as Cardan angles

- RPY can be confusing. There are two reasons.

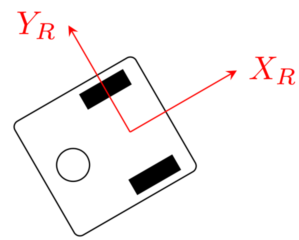
1. There are two conventions, each specifying a different sequence of axes about which to rotate:
   - $Z\ Y\ X$ normally used with vehicles
   - $X\ Y\ Z$ normally used with end-effectors

2. The angles are specified in the order yaw, pitch, roll (despite the name roll-pitch-yaw)

Specifying Orientation

That said, there are several conventions for the way these rotations are specified

Roll-Pitch-Yaw (RPY) with vehicles $Z\ Y\ X$

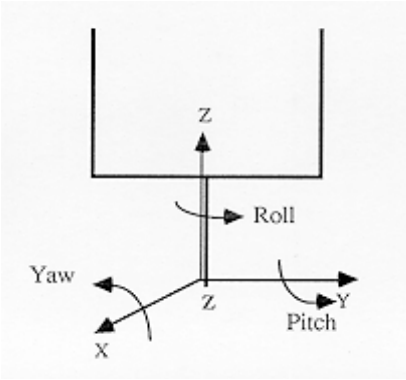


- The frame embedded in an vehicle normally has
  - X axis in the direction of travel
  - Z axis directly up
  - Y axis specified a right-hand system
- The orientation is specified by $RPY\ (\theta_y, \theta_p, \theta_r) = Rot\ (Z, \theta_y)\ Rot\ (Y, \theta_p)\ Rot\ (X, \theta_r)$
  - First, rotate the yaw angle θ_y about the Z axis (i.e. about the vertical, thus specifying the direction of travel)
  - Second, rotate the pitch angle θ_p about the Y axis (thus specifying the angle of ascent or descent)
  - Third, rotate the roll angle θ_r about the X axis (thus specifying the banking angle)

Specifying Orientation

That said, there are several conventions for the way these rotations are specified

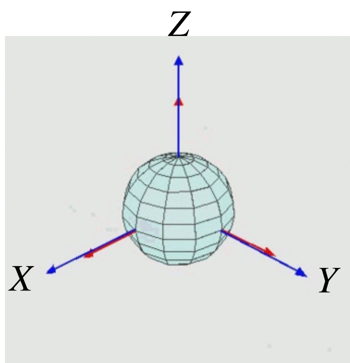
Roll-Pitch-Yaw (RPY) with end-effectors X Y Z



- The frame embedded in an end-effector or two-finger gripper normally has
  - X axis in the normal direction (i.e. normal to the movement of the fingers)
  - Z axis directed in the approach direction
  - Y axis direction in the orientation direction (i.e. parallel to the movement of the fingers)
- The orientation is specified by $RPY\ (\theta_y, \theta_p, \theta_r) = Rot\ (X, \theta_y)\ Rot\ (Y, \theta_p)\ Rot\ (Z, \theta_r)$
  - First, rotate the yaw angle θ_y about the X axis (i.e. about the normal)
  - Second, rotate the pitch angle θ_p about the Y axis (about the orientation)
  - Third, rotate the roll angle θ_r about the Z axis (about the approach)

Specifying Orientation
Euler Angles

- There are other commonly-used conventions for specifying the orientation of objects/frames
  - For example: Euler angles (e.g. rotation about Z, X, Z axes, in that order)



https://en.wikipedia.org/wiki/Euler_angles

  - Note that there are twelve Euler angle conventions; this is just one of them

- Later, we introduce quaternions, the approach used in ROS

Recommended Reading

D. Vernon, Machine Vision – Automated Visual Inspection and Robot Vision, Prentice Hall International, 1991. Chapter 8.

http://vernon.eu/publications/91_Vernon_Machine_Vision.pdf

R. P. Paul, *Robot Manipulators – Mathematics, Programming, and Control*, MIT Press, 1981. Chapter 1.

https://books.google.rw/books?id=UzZ3LAYqvRkC&printsec=frontcover&source=gbs_ViewAPI&redir_esc=y#v=onepage&q&f=false