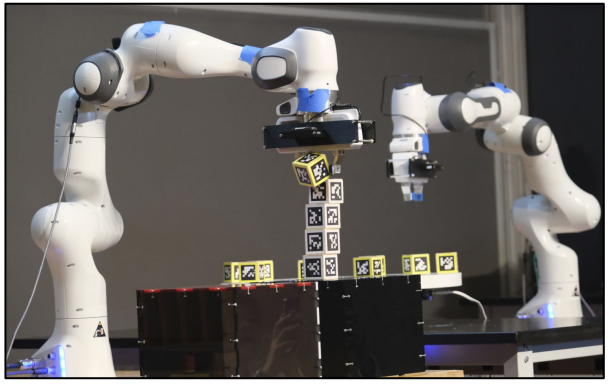
Pick and Place Task using Franka Panda Arm

Project Scope

Develop inverse kinematic solver for pick-place task **(7 DOF)**.

Detect the objects using April-tag based vision system.

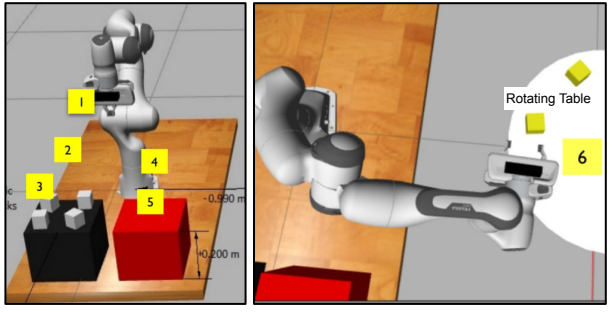
Maximize the number of blocks stacked in 5 min.



Path Planning

Predefined poses to reduce **IK computation time**.

Separate strategies for **static vs. dynamic** block grasping.



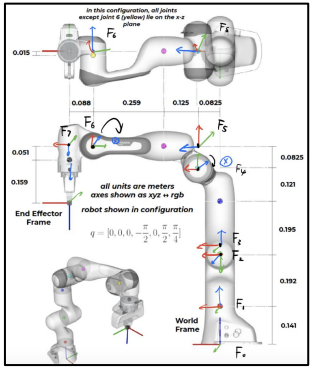
Vision System - April Tags

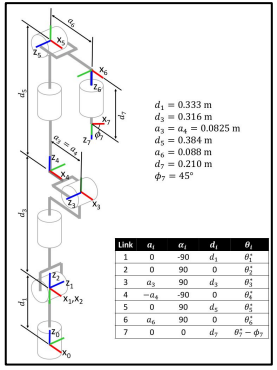
PnP pose estimation algorithm. Transformation Matrix:

$$H_{block}^{arm} = H_{ee}^{arm} . H_{camera}^{ee} . H_{block}^{camera}$$

Iterative Inverse Kinematic Solver

Coordinate Frames and D-H Parameters:





Link	a_i	α_i	d_i	θ_i
1	0	-90	d_1	θ_1^*
2	0	90	0	θ_2^*
3	a_3	90	d_3	θ_3^*
4	$-a_4$	-90	0	θ_4^*
5	0	90	d_5	θ_5^*
6	a_6	90	0	θ_6^*
7	0	0	d_7	$\theta_7^* - \phi_7$

Underdetermined System of Linear Eqs. – Pseudoinverse (n>6)

$$\mathbf{J}(q)\dot{q} = \xi, \text{ given } \xi \text{ solve for } \dot{q}, \quad \text{null}(\mathbf{J}(q)) \neq 0$$

$$\text{with } \mathbf{J}(q) \in \mathbb{R}^{6\times n}, \dot{q} \in \mathbb{R}^{n\times 1}, \xi \in \mathbb{R}^{6\times 1}$$

$$\{\dot{q} \mid \mathbf{J}(q)\dot{q} = \xi\} = \{\dot{q}^* + z | z \in \text{null}(\mathbf{J}(q))\}$$

$\dot{q}^*$ is one particular solution to $\dot{\xi} = J(\bar{q})\dot{q}$

z can be used to optimize a secondary task such as obstacle, singularity or joint limit avoidance!

How do we solve for $\dot{q}^*$?

The IK pseudoinverse is $\dot{q} = J^T(JJ^T)^{-1}\dot{\xi} = J^+\dot{\xi}$ is the minimum norm $\|\dot{q}\|$ solution $\dot{\xi} = J(\bar{q})\dot{q}$

How do we define z ?

Nullspace projection operator $z = (I - \mathbf{J}(q)^\dagger \mathbf{J}(q))b, \forall b \in \mathbb{R}^n$

For a small time step, incremental joint angle value:

q = initial configuration
while $error > \epsilon$ and $iter < iter_{max}$ **do**
  Calculate error e as a funciton of $\mathbf{T}_n^0(q) - \mathbf{H}$
  Calculate gradient J^+e
  $\Delta q = \alpha J^+ e$
  Update $q = q + \Delta q$
end while

$$b_i = -k_1\left(\frac{q_i - \bar{q}_i}{q_i^+ - q_i^-}\right), k_1 > 0 \qquad \Delta q = J^+e + (I - J^+J)b$$

Pseudocode

Initialize robot, gripper, vision system, and transformation matrices.
while task active **do**
  GoTo Capture image pose, detect static blocks, save transform positions.
  for each static block **do**
    Move to scan → grasp → stack.
  end for
  while true **do**
    Move to wait position, detect block, compute grasp pose
    grasp block, Solve IK (DLS), stack.
  end while

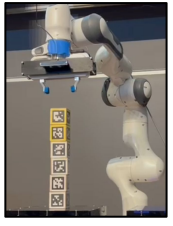
end while
Return to home position, display results

Key Challenges & Solutions

Challenge	Solution
Singularity avoidance	Damped least squares method.
Block orientation	Geometric trick for gripper alignment.
Dynamic block timing	Wait-and-pick strategy.
Gripper-table collision	10° gripper tilt .

Results

Stacked 6 blocks in 5 mins:
90 seconds to grab/stack 4 static blocks.
210 seconds for the dynamic blocks.
Competition winners!



Key Learnings

Accurate mathematical implementation is critical.

Understanding of April Tags and coordinate transformations.

Lighting conditions affect vision system performance.

Future Work

Optimize vision system for dynamic blocks.

Quantify vision system noise.

Use April Tags for platform detection as well.