Arm-Type Robots

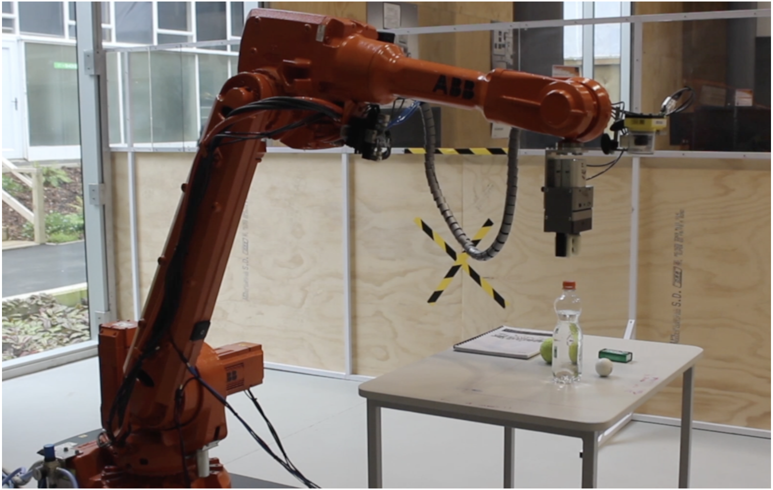
Wei Qi Yan

Auckland University of Technology

Table of Contents

Robot Arm Kinematics

AUT Robot Arm



Robot Arm

- Arm-type robots or robot manipulators have a static base and therefore operate within a limited workspace.
- A robot manipulates objects using its end-effector.
- A serial-link manipulator comprises a chain of mechanical links and joints.
- Each joint can move its outward neighbouring link with respect to its inward neighbour.
- One end of the chain, the base, is generally fixed and the other end is free to move in space and holds the tool or end-effector.

Corke, P. (2023) Robotics, Vision & Control. Springer.

Robot Arm Kinematics

Robot Arm

- A serial-link manipulator comprises a set of bodies, called links, in a chain and connected by joints.
- Each joint has one degree of freedom (DoF), either translational (a sliding or prismatic joint) or rotational (a revolute joint).
- Motion of the joint changes the relative angle or position of its neighbouring links.
- The joints of most robots are revolute.

Corke, P. (2023) Robotics, Vision & Control. Springer.

Robot Arm Kinematics

Robot Arm

- A link is considered a rigid body that defines the spatial relationship between two neighbouring joint axes.
- A link can be specified by two parameters: Its length and its twist.
- The link offset is the distance from one link coordinate frame to the next along the axis of the joint.
- The joint angle is the rotation of one link with respect to the next about the joint axis.

Corke, P. (2023) Robotics, Vision & Control. Springer.

6-DOF Robot

- Truly useful robots have a task space enabling arbitrary position and attitude of the end-effector.
- The task space has six spatial degrees of freedom (DoF): Three translational and three rotational.
- We shift the origin of the robot from the point inside the robot to the base of the pedestal using a base transform.

A small robot with a big performance designed to meet the trend towards the manufacture of miniaturized electronics and wearable devices. With the highest payload of 1.5kg, class-leading precision 0.01mm, and 30% smaller size, the IRB 1010 allows for the highest productivity and high-quality manufacturing.

Robot kinematics

- In robotics, robot kinematics applies geometry to the movement of multi-DoF kinematic chains that form the structure of robotic systems.
- Robot kinematics studies the relationship between the dimensions and connectivity of kinematic chains and the position, velocity and acceleration of each of the links in the robotic system, in order to plan and control movement and to compute actuator forces and torques.
- There are two broad classes of robots: Serial manipulators and parallel manipulators.
- The time derivative of the kinematics yields the **Jacobian** of the robot, which relates the joint rates to the linear and angular velocity of the end-effector.

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

Robot Arm Kinematics

Forward Kinematics

- The forward kinematics is often expressed in functional form with the end-effector pose as a function of joint coordinates.
- The forward kinematic solution can be computed for any serial-link manipulator irrespective of the number of joints or the types of joints.
- The simple two-link robot is limited in the poses that it can achieve.

Corke, P. (2023) Robotics, Vision & Control. Springer.

Inverse Kinematics

- **Forward Kinematics (FK)** uses the joint parameters to compute the configuration of the chain.
- **Inverse Kinematics (IK)** reverses this calculation to determine the joint parameters that achieve a desired configuration

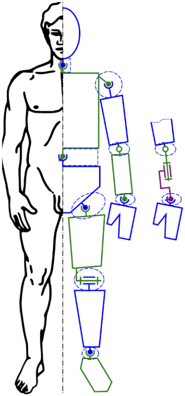
Note: A pose may also be unachievable due to singularity where the alignment of axes reduces the effective degrees of freedom. Hence, we need choose a trajectory that moves through a robot singularity.

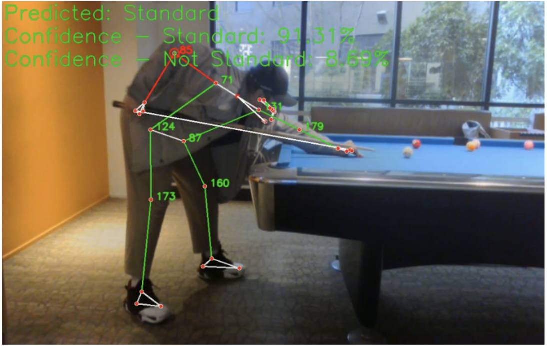
https://en.wikipedia.org/wiki/Inverse_kinematics

Robot Arm Kinematics

Inverse Kinematics

Inverse kinematics is an example of the kinematic analysis of a constrained system of rigid bodies, or kinematic chain.





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

MATLAB Inverse Kinematics

- Kinematics is the study of motion without considering the cause of the motion.
- Inverse kinematics is the use of kinematics to determine the motion of a robot to reach a desired position.
- The grasping end of a robot arm is designated as the end-effector.
- The robot configuration is a list of joint positions that are within the position limits of the robot model and do not violate any constraints the robot has.
- Given the desired end-effector positions, inverse kinematics (IK) can determine an appropriate joint configuration for which the end-effectors move to the target pose.

https://au.mathworks.com/help/robotics/ug/2d-inverse-kinematics-example.html

MATLAB Inverse Kinematics

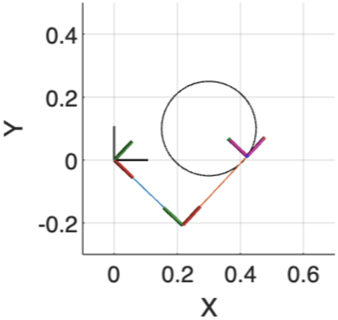
- MATLAB inverse kinematics for a simple 2D manipulator using the inverse Kinematics class.
- The manipulator robot is a simple 2-DoF planar manipulator with revolute joints.
- A circular trajectory is created in a 2D plane and given as points to the inverse kinematics solver.
- The solver calculates the required joint positions to achieve this trajectory.
- The robot is animated to show the robot configurations that achieve the circular trajectory.

https://au.mathworks.com/help/robotics/ug/2d-inverse-kinematics-example.html

Robot Arm Kinematics

MATLAB Inverse Kinematics

MATLAB 2D Path Tracing with Inverse Kinematics (IK)



https://au.mathworks.com/help/robotics/ug/2d-inverse-kinematics-example.html

Questions?

Questions?

Regarding robotic arm, each joint has one degree of freedom,

1. either translational or rotational.
2. both translational and rotational.
3. neither translational nor rotational.
4. None of the given options.

The right answer is:____.

Questions?

Dynamics and Control

Robot dynamics are the relationship between the forces acting on a robot and the resulting motion of the robot.

Robotics usually combines three aspects of design work to create robot systems:

- **Mechanical construction**: A frame, form or shape designed to achieve a particular task.
- **Electrical components**: Power and control the machinery.
- **Software**: A program for a robot to decide when or how to conduct actions.

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

Dynamics and Control

Robot dynamics are the relationship between the forces acting on a robot and the resulting motion of the robot.

- **Electric motors**: DC motors in portable robots or AC motors in industrial robots.
- **Actuators**: Convert stored energy into movement.
- **Sensors**: Provide real-time information.
- **Manipulation**: Control of its environment through selective contact.
- **End effector**: The device at the end of a robotic arm, designed to interact with the environment.

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

Dynamics and Control

The interaction between human control and the machine motions:

- **Teleoperation**: A human controls each movement, each machine actuator change is specified by the operator.
- **Supervisory**: A human specifies general moves or position changes and the machine decides specific movements of its actuators.
- **Task-level autonomy**: The operator specifies only the task and the robot manages itself to complete it.
- **Full autonomy**: The machine will create and complete all its tasks without human interaction.

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

Dynamics and Control

In the dynamics and control of a serial-link manipulator, each link is supported by a reaction force and torque from the preceding link, which is subject to its own weight as well as the reaction forces and torques from the links that it supports.

We have the joint torques and forces applied directly as a vector to each joint.

$$\mathbf{Q} = \mathbf{M}(q)\ddot{q} + \mathbf{C}(q,\dot{q})\dot{q} + \mathbf{G}(q) + \mathbf{J}(q)^{\tau} \cdot \mathbf{F}_{Ext}$$

where $\mathbf{G}(q)$ is gravity term, $\mathbf{M}(q)\ddot{q}$ is inertia matrix, $\mathbf{C}(q,\dot{q})\dot{q}$ is centrifugal torques, $\mathbf{J}(q)^{\tau} \cdot \mathbf{F}_{Ext}$ is the external force, $\mathbf{J}$ is the Jacobian matrix of the end effector.

https://au.mathworks.com/help/robotics/ug/robot-dynamics.html

Dynamics and Control

The individual link is quite complex but for the series of links, we have the joint torques and forces applied directly as a vector to each joint as

$$\mathbf{Q} = \mathbf{M}(q)\ddot{q} + \mathbf{C}(q, \dot{q})\dot{q} + \mathbf{G}(q) + \mathbf{J}(q)^{\tau} \cdot \mathbf{F}_{Ext}$$

where $\mathbf{G}(q)$ is gravity term, $\mathbf{M}(q)\ddot{q}$ is inertia matrix, $\mathbf{C}(q, \dot{q})\dot{q}$ is centrifugal torques, $\mathbf{J}(q)^{\tau} \cdot \mathbf{F}_{Ext}$ is the external force, $\mathbf{J}$ is the Jacobian matrix of the end effector.

In inverse dynamics, given the pose q, velocity $\dot{q}$ and acceleration $\ddot{q}$, this equation can be applied to compute the required joint forces or torques.

https://au.mathworks.com/help/robotics/ug/robot-dynamics.html

Questions?

Questions?

Regarding the interaction between human control and the machine motions, the full autonomy is:

1. The machine will create and complete all its tasks without human interaction.
2. A human specifies general moves or position changes and the machine decides specific movements of its actuators.
3. The operator specifies only the task and the robot manages itself to complete it.
4. None of the given options.

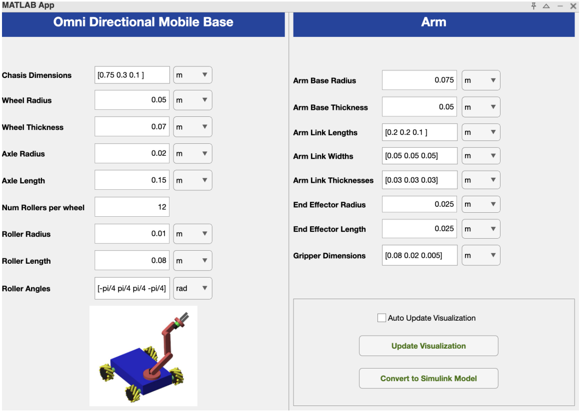
The right answer is:___

Questions?

Dynamics and Control

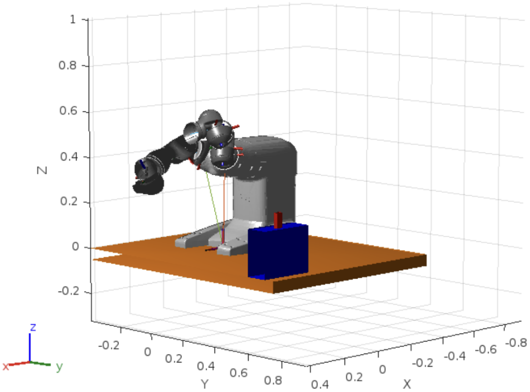
MATLAB Mobile Arm

Interactive design for a mobile manipulator with four omni-directional wheels.



https://au.mathworks.com/help/sm/ug/mobile_robot_app.html

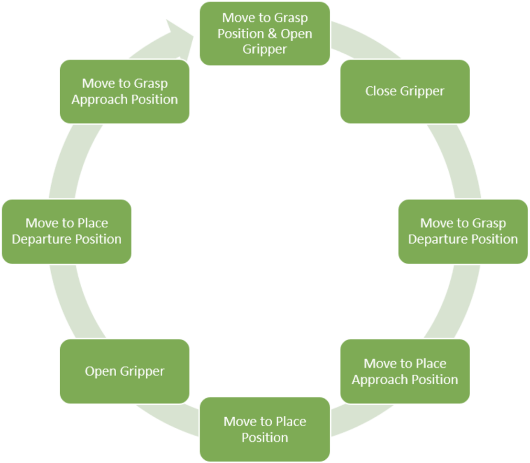
MATLAB ABB YuMi Robot



https://au.mathworks.com/help/robotics/ug/model-and-control-a-manipulator-arm-with-simscape.html

MATLAB ABB YuMi Robot

The eight states of a robot:



https://au.mathworks.com/help/robotics/ug/model-and-control-a-manipulator-arm-with-simscape.html

MATLAB ABB YuMi Robot

The design is split into four sections:

- Define a Robot and Environment
- Create a Task & Trajectory Scheduler
- Add Core Manipulator Dynamics and Design a Controller
- Verify Complete Workflow of the Robot and Environment.

https://au.mathworks.com/help/robotics/ug/model-and-control-a-manipulator-arm-with-simscape.html

Questions?

Learning Objectives

- Derive solutions for particular robotic vision and visual control tasks characterised by specifics of image data and deep learning algorithms.
- Demonstrate critical thinking in designing problem solutions for tasks in robotics.