Universität
Bremen

Institute for Artificial Intelligence
Faculty 03
Mathematics &
Computer Science

Robot Programming with ROS

4. Motors and Kinematics

Arthur Niedźwiecki, Stefan Eirich
09th Nov. 2023

EASE

Artificial Intelligence

Overview

Overview

What makes a robot?

A Robot is an electro-mechanical device, composed of a collection of bodies (links), which are combined by joints. A robot is equipped with actuators (motors), that can move neighbouring links relative to each other by exerting forces.

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Robots are equipped with control programs that are designed to accomplish tasks by moving the body of the robot in a task-driven way.

The control software will be addressed in subsequent modules.

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Basic Principles

- Position the End effector (Move the end effector in the room)
- Touch objects (Manipulation)
- Exercise a force on the ground relative to itself (Move in the plane)

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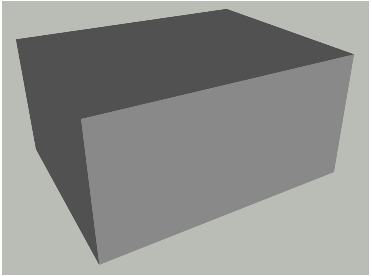
Links

Rigid body with visual and collision features and known inertia properties.

```
<link name="${name}">
    <visual>
        <geometry>
            <box size="${base_length} ${base_width} ${
              base_height}"/>
        </geometry>
        <material name="LightGrey">
            <color rgba="0.7 0.7 0.7 1.0"/>
        </material>
    </visual>
    <collision>
        <geometry>
            <box size="${base_length} ${base_width} ${
              base_height}"/>
        </geometry>
    </collision>
    <inertial>
        <origin xyz="0 0 0.5" rpy="0 0 0"/>
        <mass value="100"/>
        <inertia ixx="100" ixy="0" ixz="0" iyy="100" iyz
            ="0" izz="100"/>
    </inertial>
</link>
```



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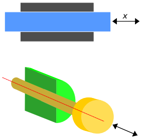
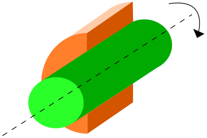
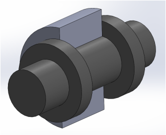
Joints

- Two type of joints: **revolute** (rotary motion) and **prismatic** (linear motion)
- Classical industrial application: high stiffness in links and joints
  - Advantage: position accuracy
  - Disadvantage: may lead to high forces exerted by robot → danger!
  - Note: link deflection under load or joint play might reduce precision in the real-world



One translational degree of freedom

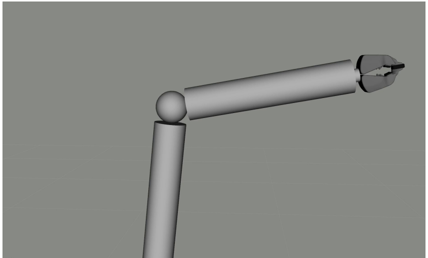




One rotary degree of freedom

Joints

```
<joint name="${prefix}shoulder_lift_joint" type="continuous">
    <parent link="${prefix}base_link"/>
    <child link = "${prefix}upper_arm_link"/>
    <origin xyz="0 0 0" rpy="0 0 0"/>
    <axis xyz="0 0 1"/>
    <limit lower="${shoulder_lift_lower_limit}" upper="${shoulder_lift_upper_limit}"
          effort="150.0" velocity="3.15"/>
    <dynamics damping="1.0" friction="100.0"/>
</joint>
```



Non-classical approach: soft robots

- Impedance control

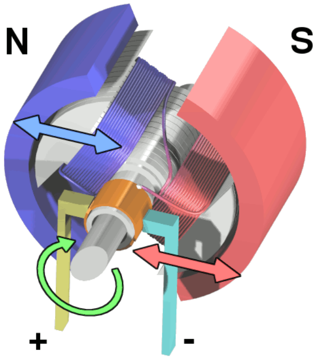
Summary

- Basic principles of robotics
- Description of links and joints

Overview

Brushed DC Motor

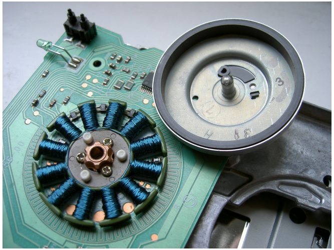
- cheap
- used in toys
- turns without motor controller
- commutation with brushes (may wear out)



Video: **LearnEngineering2014SepDCMotorHow**

Brushless DC Motor

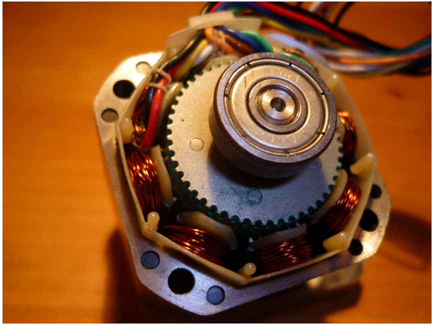
- cheap as well
- used e.g. in CD-ROM drives
- electronic commutation necessary (with sensors or sensorless)
- coils can be inside or outside (better cooling when outside)



Video: **LearnEngineering2014OctBrushlessDCMotor**

Stepper Motor

- very standardized
- strong at low speeds
- used in printers
- moves repeatably
- feed-forward by nature
- “looses steps” when friction/inertia/... is too high ...
- ... or is moving at its resonance frequency



Video: **LearnEngineering2016OctHowDoesStepper**

Overview

Robot Arm

Sequence of links connected by joints and moved relative to each other by actuators.

Robot Arm

```
<xacro:macro name="simple_arm" params="prefix parent *origin joint_limited:=true">

    <joint name="shoulder_pan_joint" type="continuous">
        <parent link="${parent}"/>
        <child link = "${prefix}base_link"/>
        <xacro:insert_block name="origin"/>
        <axis xyz="0 1 0"/>
        <limit lower="${shoulder_pan_lower_limit}" upper="${shoulder_pan_upper_limit}" effort="150.0" velocity="3.15
              "/>
        <dynamics damping="1.0" friction="100.0"/>
    </joint>

    <link name="${prefix}base_link">
        <visual>
            <origin xyz="0 0 0" rpy="0 0 ${base_correction}"/>
            <geometry>
                <sphere radius="${base_radius}"/>
            </geometry>
            <material name="LightGrey">
                <color rgba="0.7 0.7 0.7 1.0"/>
            </material>
        </visual>
        <collision>
            <origin xyz="0 0 0" rpy="0 0 ${base_correction}"/>
            <geometry>
                <sphere radius="${base_radius}"/>
            </geometry>
        </collision>
        <xacro:sphere_inertial radius="${base_radius}" mass="${base_mass}">
            <origin xyz="0.0 0.0 0.0" rpy="0 0 0"/>
        </xacro:sphere_inertial>
    </link>

[...]

</xacro:macro>
</robot>
```

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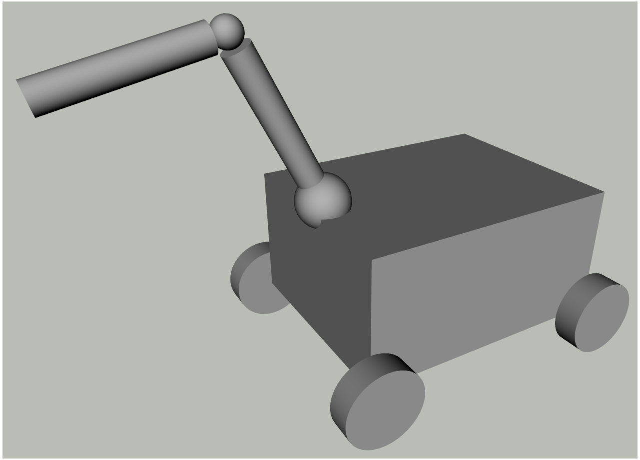
Robot Arm



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Overview

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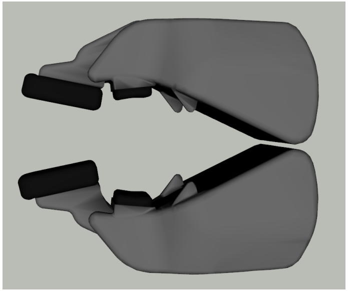
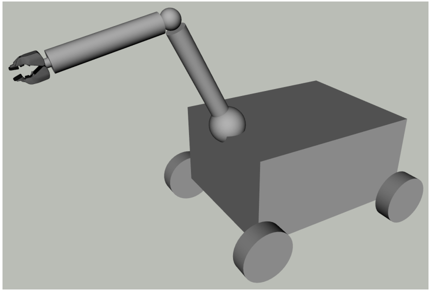
Gripper

Touch objects and interact with the environment.

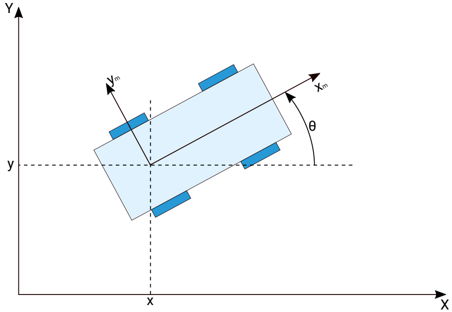




Overview

Wheeled Locomotion

Goal: Bring the robot to a desired pose (x, y, θ):
(position in **x**-axis, position in **y**-axis, **angle** with x-axis)
$\Rightarrow$ 3 Degrees of Freedom (DOF)



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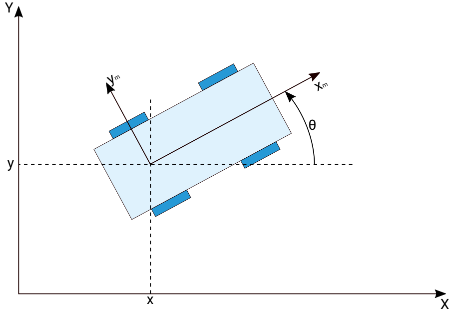
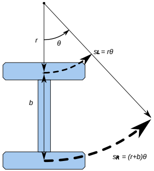


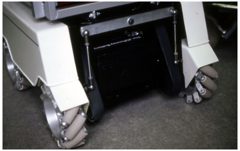
Wheeled motion typically has **non-holonomic constraints**

Wheel Types

Fixed wheels



Mecanum wheels



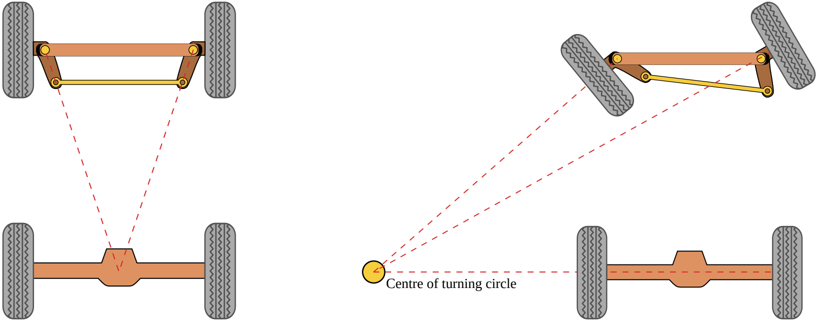
Omniwheels

Video

,

Ackerman steering

- Car-like steering
- \+ Robust
- \+ Outer wheels moves on a circle of different radius than inner wheel
- – But hard to control (parking!)



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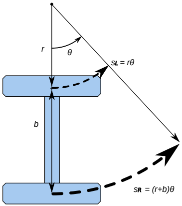
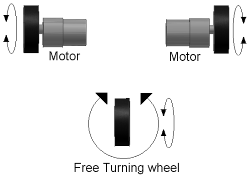
Differential-Drive

+ Turns on spot
+ Good choice for round robots
+ Parking is easier
– Cannot move sidewards





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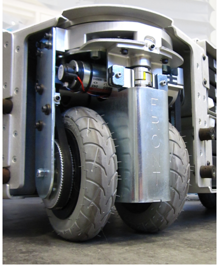
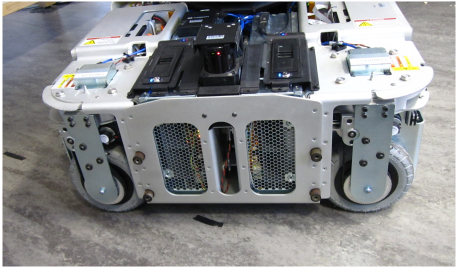
Turnable wheels

- + Omnidirectional (can drive forwards, sideways and turn)
- – On change of direction, requires 'reconfiguration' of its wheels.
- → Controllers should not oscillate





PR2: Double wheel construction to reduce friction while turning the wheel

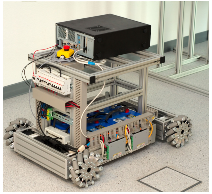
"Omniwheels"

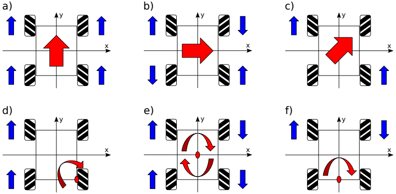
- \+ Omnidirectional (can drive forwards, sideways and turn)
- Wheels have free rollers at **90**^{o}
- \+ Three wheels are enough
- – Hard to make them run smooth

Rotacaster
Source: `https://en.wikipedia.org/w/index.php?title=Omni_wheel&oldid=1013193962`

Mecanum-Wheels

+ Omnidirectional (can drive forwards, sideways and turn)
- Wheels have free rollers at **45**^{o}
+ No reconfiguration is involved
– Depending on wheels, requires flat ground





Linearity ⇒

A (linear) combination of cartesian movements can be achieved with the linear combination of the respective wheel velocities.

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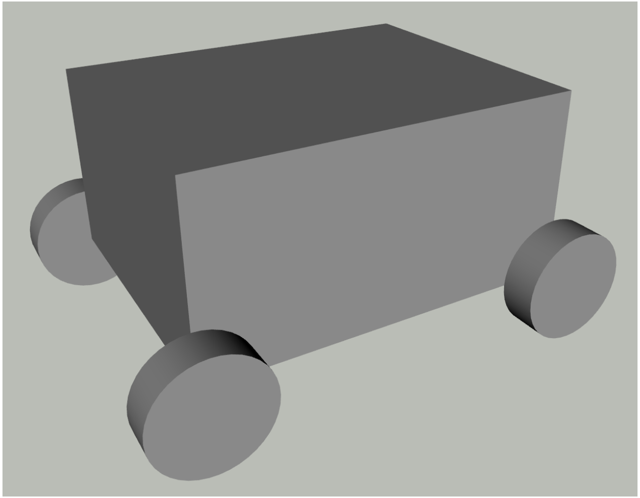
Mobile Base

```
<xacro:simple_robot_base name="base_link">
</xacro:simple_robot_base>

<xacro:omni_wheel name="omni_wheel_fl" parent="base_link">
    <origin xyz="${0.5*base_length} ${0.5*base_width + 0.5*wheel_thickness}
        ${-0.5*base_height}" rpy="${pi/2} 0 0"/>
</xacro:omni_wheel>

<xacro:omni_wheel name="omni_wheel_fr" parent="base_link">
    <origin xyz="${0.5*base_length} ${-0.5*base_width - 0.5*wheel_thickness}
        ${-0.5*base_height}" rpy="${pi/2} 0 0"/>
</xacro:omni_wheel>

<xacro:omni_wheel name="omni_wheel_bl" parent="base_link">
    <origin xyz="${-0.5*base_length} ${0.5*base_width + 0.5*wheel_thickness}
        ${-0.5*base_height}" rpy="${pi/2} 0 0"/>
</xacro:omni_wheel>

<xacro:omni_wheel name="omni_wheel_br" parent="base_link">
    <origin xyz="${-0.5*base_length} ${-0.5*base_width - 0.5*wheel_thickness}
        ${-0.5*base_height}" rpy="${pi/2} 0 0"/>
```

Mobile Base



Summary

- Actuation of robot arms
- Wheeled locomotion

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Overview

Kinematics

- Joint Space
- Task Space (Workspace)
- Forward Kinematics
- Inverse Kinematics

Configuration Space

Configuration

The **configuration** of a robot is a complete specification of the positions of every point of the robot.

“How can we represent the configuration?”

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Configuration Space

Degrees of Freedom

The number of **degrees of freedom** is the minimum number of independent parameters needed to represent the configuration of the robot.

It is equivalently called the **mobility** of the robot.

Configuration Space

Degrees of Freedom

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It is equivalently called the **mobility** of the robot.

Configuration Space

If the robot has n degrees of freedom, the n-dimensional space containing all possible configurations of the robot is called the **configuration space**.

The robot's configuration is usually expressed in terms of joint variables, so the configuration space is also called the **joint space**.

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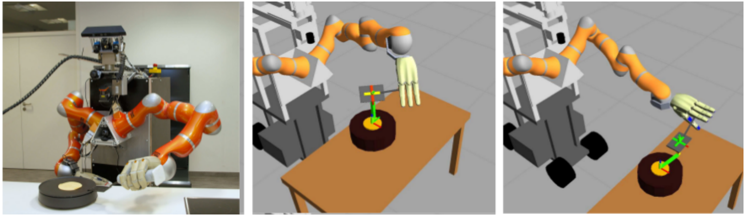
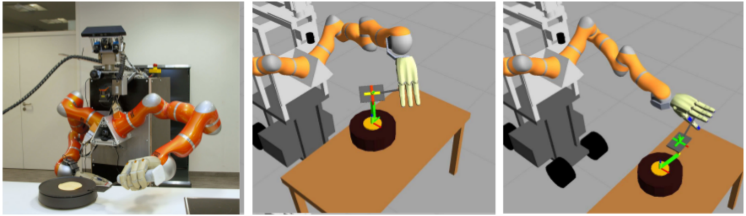
Configuration Space vs. Task Space



How can we get the *configuration/joint* trajectory to do this?

Configuration Space vs. Task Space



- The robot interacts with **objects** and **obstacles** which are better defined by an external set of coordinates (*e.g.*, (**x**, **y**, **z**) coordinates in a **global frame**.)

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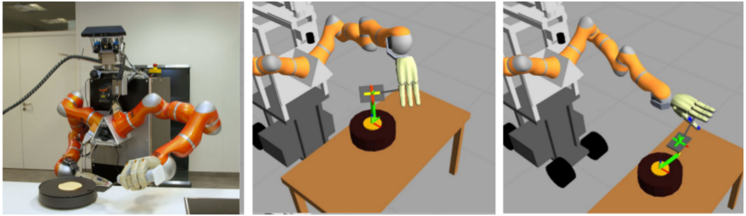
Configuration Space vs. Task Space



- The robot interacts with **objects** and **obstacles** which are better defined by an external set of coordinates (*e.g.,* (**x**, **y**, **z**) coordinates in a **global frame**.)
- The part interacting with environments such as obstacles and objects is called the **end-effector**.

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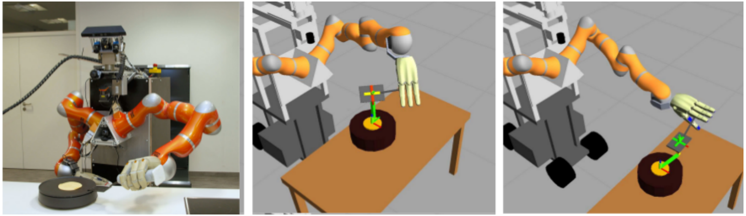
Configuration Space vs. Task Space



- The robot interacts with **objects** and **obstacles** which are better defined by their coordinates (*e.g.*, (**x**, **y**, **z**) Euclidean 3D coordinates in a **world frame**.)
- The part interacting with environments such as obstacles and objects is called the **end-effector**.
- It is useful to attach a coordinate frame to the **end-effector** and command the pose of the end-effector in the world/object frame.

Task Space aka Operational Space

Operational Space

Given a robot with a reference frame attached to its end-effector, the **operational space** is the set of all positions and/or orientations achievable by the end-effector frame.

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Required degrees of freedom

How many degrees of freedom do we need?

Required degrees of freedom

How many degrees of freedom do we need? (It depends on the task!)

- pointing a camera: 2 DOF
- placing an object (only position is important): 3 DOF
- placing an object (position and orientation): 6 DOF
- imitating a human arm: 7 DOF (from shoulder ball joint)

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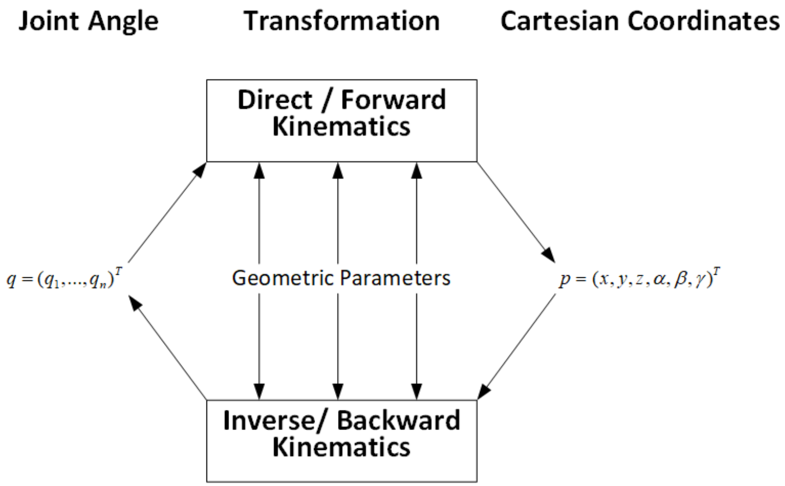
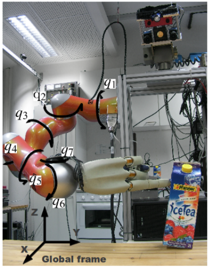
Robot kinematics



Forward Kinematics

Forward Kinematics Problem

Given an open-chain robot arm with a prescribed task frame, the goal is to determine the task frame's position and orientation as a function of the joint values.



Given: $(q_1, q_2, \cdots, q_7)$

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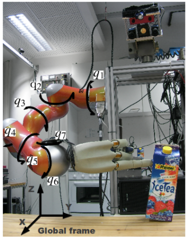
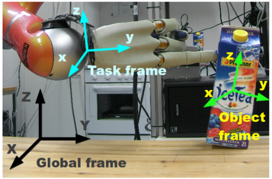


Forward kinematics →



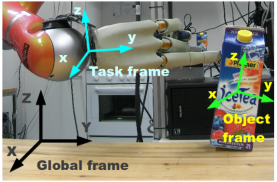
Given: $(q_1, q_2, \cdots, q_7)$ Calculate: $(x, y, z, \alpha, \beta, \gamma)$

For a given set of joint angles there will usually exist a **unique** end-effector position

Inverse Kinematics

Inverse Kinematics Problem

Given a desired position and orientation of the end-effector frame, one seeks to determine the set of joint angles that achieves this desired end-effector configuration.



Given: $(x, y, z, \alpha, \beta, \gamma)$

Inverse Kinematics

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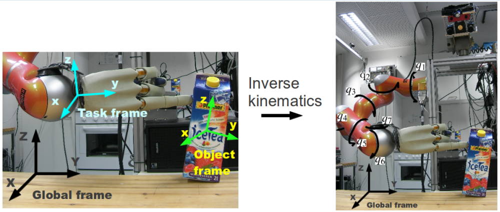

Given: $(x, y, z, \alpha, \beta, \gamma)$ Calculate: $(q_1, q_2, \cdots, q_7)$

For a particular end-effector position and orientation, there may exist **multiple** solutions, or even **none** at all. (*e.g.*, *elbow-up* and *elbow-down* configurations)

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Kinematics – An Example

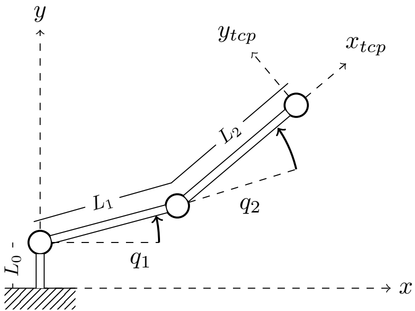

Figure: Two links planar manipulator

- Forward kinematics :

$$\begin{pmatrix} x_{tcp} \\ y_{tcp} \end{pmatrix} = \begin{pmatrix} L_1 \cos q_1 + L_2 \cos(q_1 + q_2) \\ L_1 \sin q_1 + L_2 \sin(q_1 + q_2) \end{pmatrix}$$

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Kinematics – An Example

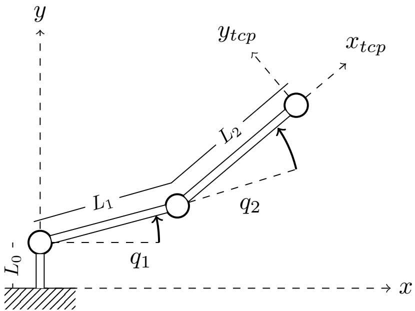

Figure: Two links planar manipulator

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- Inverse kinematics :

$$\alpha = \cos^{-1}\left(\frac{x_{tcp}^2 + y_{tcp}^2 + L_1^2 - L_2^2}{2L_1\sqrt{x_{tcp}^2 + y_{tcp}^2}}\right),\ \beta = \cos^{-1}\left(\frac{L_1^2 + L_2^2 - x_{tcp}^2 - y_{tcp}^2}{2L_1 L_2}\right)$$

$$q_1 = \tan^{-1}\frac{y_{tcp}}{x_{tcp}} - \alpha,\ q_2 = \pi - \beta$$

$$q_1 = \tan^{-1}\frac{y_{tcp}}{x_{tcp}} + \alpha,\ q_2 = \pi + \beta$$

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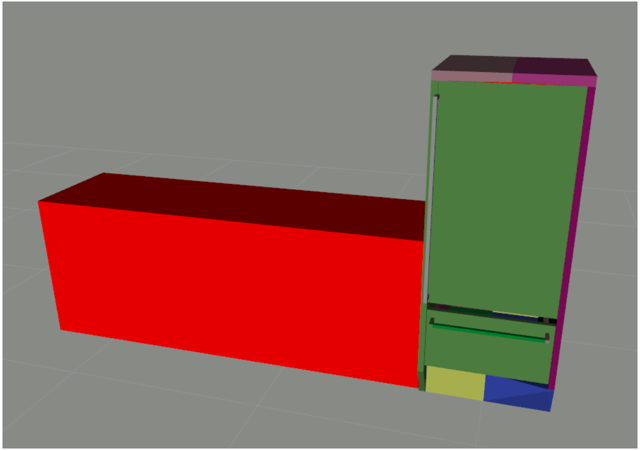
Overview

The Representation Of The Environment



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09th Nov. 2023
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Summary

- Configuration and task space
- Robot kinematics

Overview

Discord

Follow this to our Discord server. Link open until 15.11.23

`https://discord.gg/yzRurKba`

Assignment and dates

- Assignment 4:
  `https://github.com/artnie/rpwr-assignments`
- Grades: 8 points for this assignment
- Due: 15.11., 23:59 AM German time
- Next class: 16.11., 14:00

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Evaluation

Thanks for your attention!

Special thanks to the IAI team for the content of this lecture!

https://forms.gle/iZyKqLCxsrwBU3XZ6