236609 - AI and Robotics - Fall 2024

What is a Robot

Sarah Keren

The Taub Faculty of Computer Science
Technion - Israel Institute of Technology

Table of contents

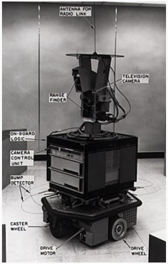
1. What is a Robot

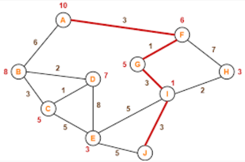
2. Workspace and Configuration Space

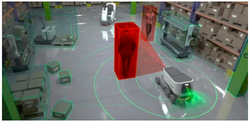
What is a Robot

Clarification

We are not supposed to dive into the details of the topics we are going to cover, but I think it's very important that CS students and researchers understand (even very abstractly) what is going on when we give the command 'go from A to B'







What does it mean to be autonomous ?

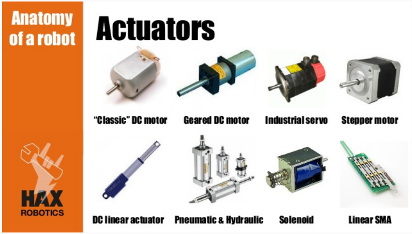
- Action (Actuation)
  - Locomotion: wheels (e.g., differential drives)
  - Manipulation: arms, grippers, etc.
- Perception (Sensors)
  - Proprioception (internal: IMU (inertial measurement unit), encoders , etc,)
  - Exteroception (external: cameras, scanners)
- Cognition (Control)
  - From reactive to proactive
  - From finite state machines to cognitive robotics

Most of the course will be about control. This lecture focuses on sensors and actuators.

Actuators

www.creativemotioncontrol.com/types-of-actuators/

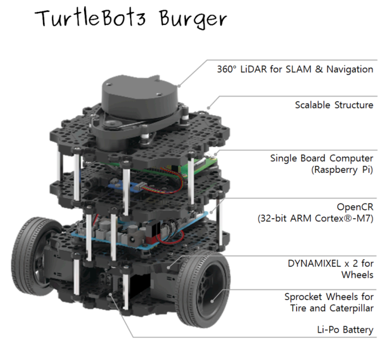
- Actuators control movements within machines.
- There are various kinds of actuators that
  - produce varying motions (linear or rotary)
  - use different power sources
    - hydraulic (with a fluid-filled cylinder)
    - pneumatic (using pressurised gases)
    - electric Actuators (popular in robotics)



https://youtu.be/LHn7O6PUaoY?t=68

The turtlebot3 burger actuators

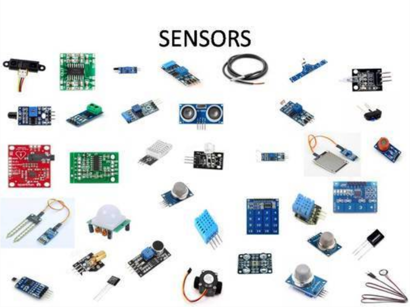
dynamixel



https://www.youtube.com/watch?v=rmqyOCefhGA https://emanual.robotis.com/docs/en/dxl/x/xl430-w250/

Sensors

- Robotic sensors are used to estimate the robot's condition and environment.
- Signals are passed to the controller to decide on the appropriate behavior.
- Robots require various sensors to function effectively.



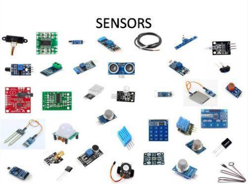
Taken from: https://www.javatpoint.com/types-of-robot-sensors

https://roboticsbiz.com/sensors-in-robotics-7-common-sensors-

Sensors

Sensors generally classified into two groups:

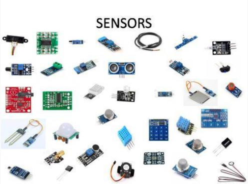
- Internal sensors
  - obtain the information about the robot itself
  - position sensor, velocity sensor, acceleration sensors, motor torque sensor, etc
- External sensors
  - gather the information in the surrounding environment.
  - cameras, range sensors (IR sensor, laser range finder, and ultrasonic sensor) contact and proximity sensors (photodiode, IR detector, RFID, touch, etc.) and force sensors



Sensors

Sensors are defined by various properties that describe their capabilities:

- Sensitivity
- Linearity
- Response time
- Measurement/dynamic range
- Accuracy
- Repeatability
- Resolution
- Bandwidth



Sensor types

- **Light sensor** is a transducer used for detecting light. It creates a voltage difference equivalent to the light intensity fall on a light sensor.
- **Proximity sensor** detects the presence of nearby object without any physical contact. It transmits an electromagnetic radiation and receives and analyzes the return signal for interruptions. The amount of light returned to the receiver is used to detect the presence of nearby object (for example, infrared (IR), ultrasonic Sensor)
- **Sound Sensor** use a microphone to detect sound and return a voltage equivalent to the sound level. Can be used for sound based navigation.
- **Temperature sensor** used for sensing the change in temperature of the surrounding.

Sensor types

- Acceleration sensor is used for measuring acceleration and tilt
  - Static Force - measures the frictional force between any two objects. By measuring this gravitational force we can determine the how much robot is tilting. This measurement is useful in balancing the robot, or for determining whether robot is driving on a flat surface or uphill.
  - Dynamic Force - measures acceleration.

Sensor types

- Detects an object's contact.
- Allows the robot to touch and feel.
- Can be sorted into two principal types:
    - **Touch Sensor:** capable of sensing and detecting sensor and object touch. Some of the commonly used simple devices are micro-switches, limit switches, etc. These sensors are mostly used for robots to avoid obstacles. When these sensors hit an obstacle, it triggers a task for the robot, which can be reversed, turned, switched on, stopped, etc.
    - **Force Sensor:** calculates the forces of several functions, such as machine loading and unloading, material handling, and so on, performed by a robot.

Sensor types

Navigation and Positioning Sensors:

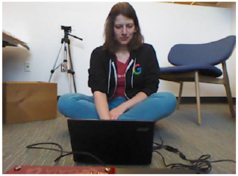
- A GPS (Global Positioning System). Satellites orbiting our Earth transmit signals, and a robot receiver acquires and processes these signals. Use the processed information to determine a robot's approximate position and velocity.
- Digital Magnetic Compass provides directional measurements using the Earth's magnetic field that guides your robot to reach its destination.

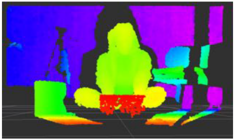
Robot Sensing

- Robots operate in human designed world!
- Cheaper and cheaper Cameras and sensors!
- But robots’ vision != computer vision (and sensing in general)
- Robots have limited computation time and not a lot of memory (real-time)
- Robots are action driven, and thus perception is task driven – can be less general (minimalism)
- Robots also have the advantage (?) that they see images and sense objects over and over while they move (e.g., video)

Vision

Many vision options: color, depth, video, and more.



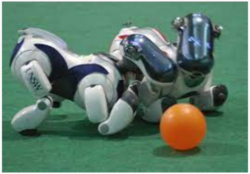


Vision

Why is vision challenging ?

Vision

Why is vision challenging ?



https://youtu.be/pfdNm3wFASE

https://www.youtube.com/watch?v=so9axknlftk

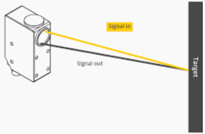
Distance Sensor

- Used for determining the proximity of an object without physical contact.
- It functions by outputting a signal (depending on technology; ultrasonic waves, IR, LED, etc.) and measuring the change when the signal returns.
- Measurement of change can be in the form of: The time it takes for a signal to return The intensity of a returned signal
- Two forms:
    - **Proximity sensors** sense if an object is within the sensing area where the sensor is designed to operate. Hence, not necessarily indicating the distance between sensor and object
    - **Distance sensors** sense distance from the object and the measuring device through outputting a current. Currents can be in the form of ultrasonic waves, laser, IR, etc.

Laser Distance Sensor

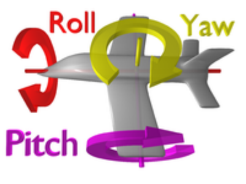
https://www.seeedstudio.com/blog/2020/01/17/what-is-imu-sensor-overview-with-arduino-usage-guide/

- Use a focused, coherent light to measure distance to a target object.
- The output signal is often highly accurate, and it includes temperature compensation to enhance stability.
- Laser light must be focused, and it must stay narrow over a great distance and at a narrow spectrum (color of light). The emitted light can then be triangulated or pulsed, with each pulse return measured to create distance readings

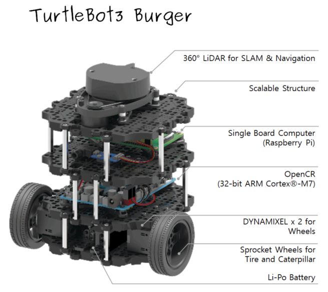


Inertial Measurement Unit (IMU)

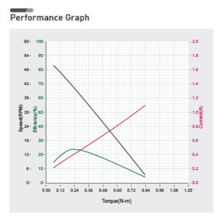
- An electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body on three-axis, commonly known as Pitch, Roll, and YAW.
- Relies on the functionality of
  - **Accelerometers** detect the rate of change in velocity of an object (can only measure pitch and roll, no information about yaw)
  - **Gyroscopes** detect rotational changes or maintaining orientation.
  - **Magnetometer** measures gravitational force
- Combining these three sensors yields an IMU that measures orientation, velocity, and gravitational force.



The turtlebot3 burger sensors



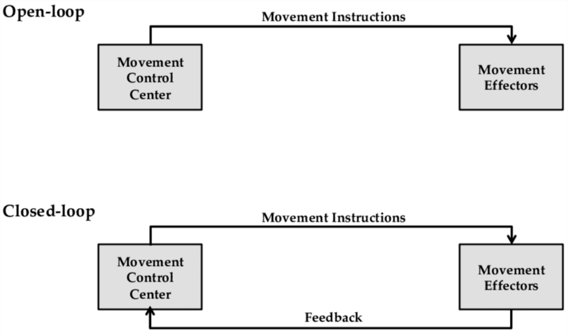
- Laser Distance Sensor
  - 360 Laser Distance Sensor LDS-01
  - 2D laser scanner capable of sensing 360 degrees
  - collects a set of data around the robot to use for Simultaneous localization and mapping (SLAM) - which we will talk about next week.
- Gyroscope 3 Axis
- Accelerometer 3 Axis
- Magnetometer 3 Axis



- Each Dynamixel contains a control table consisting of data registers that are readable and writable.
- Readable registers can provide feedback regarding the status of Dynamixel, including information regarding:
    - internal temperature,
    - position,
    - speed,
    - torque,
    - voltage, etc.
- By enabling the Alarm Shutdown and Alarm LED registers, Dynamixel can protect itself against overheating, overload, etc.

Closed vs. open loop control

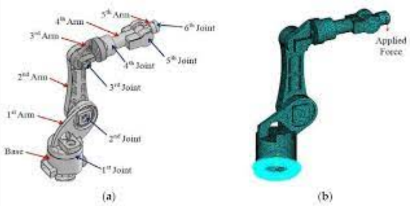
- **Open loop control**: Take a fixed sequence of actions, e.g. Driving in a square (did that work with the turtlebot ?).
- **Closed loop control**:
  - Desired state (goal state, setpoint)
  - Feedback (i.e. measured - desired)
  - Classic Example: Thermostat



Workspace and Configuration Space

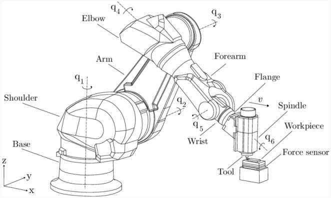
Configuration

- The **configuration** of a robot is a complete specification of the position of every point of the robot.
- A configuration q is **collision-free**, or free, if the robot placed at q does not intersect any obstacles.



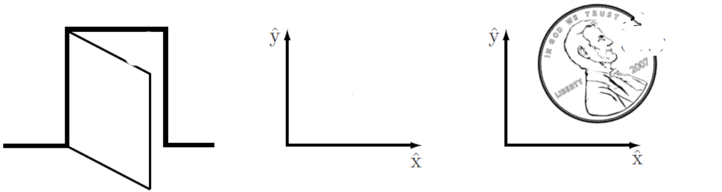
Degrees of Freedom (dof)

- The **degrees of freedom (dof)** of a robot are the minimum number *n* of real-valued coordinates needed to represent the configuration of a robot.
- A mechanism is typically constructed by connecting rigid bodies, called **links**, together by means of **joints**, so that relative motion between adjacent links becomes possible.
- **Actuation** of the joints, typically by electric motors, then causes the robot to move and exert forces in desired ways.
- dof typically refers to the number of movable joints of a robot.



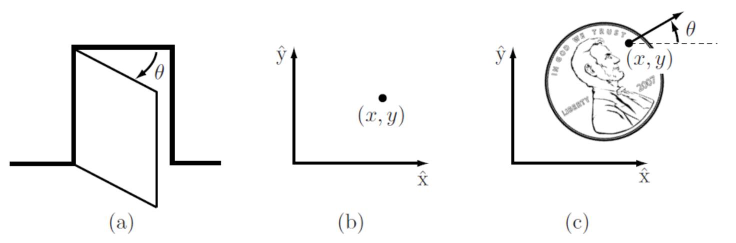
Degrees of Freedom (dof)

What’s the dof ?



(a) (b) (c)

Degrees of Freedom (dof)



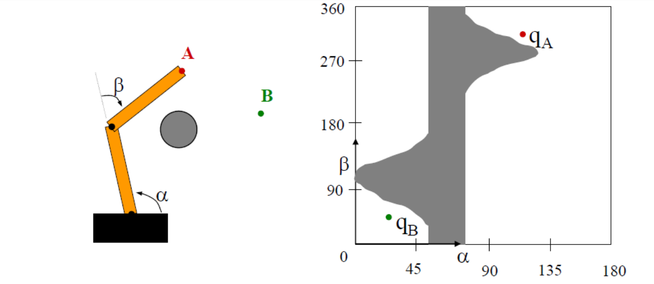
The configuration of a door is described by the angle θ (b) The configuration of a point in a plane is described by coordinates (x, y). (c) The configuration of a coin on a table is described by (x, y, θ), where θ defines the direction in which Abraham Lincoln is looking.

Configuration space, work space and task space

We are going to consider three space representations:

- The **workspace** is a specification of the robot's possible configurations in the environment.
- The **configuration space (C-space)** is a specification of the robot's attainable positions in the environment. It is the n-dimensional space containing all possible configurations of the robot.
- The **task space** is the space in which the robot's task can be naturally expressed.

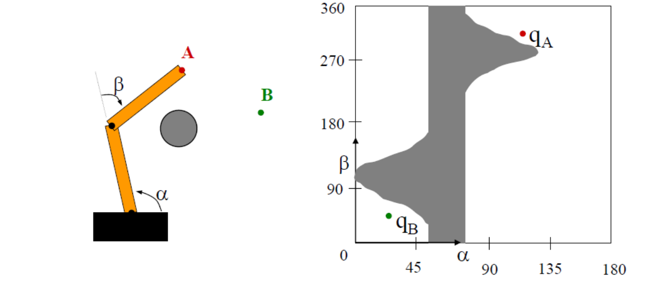
Configuration space, work space and task space: example



- This robot arm has two joints that move independently.
- Moving these joints alters the coordinates of the elbow and the gripper.

What's the workspace, configuration space and task space here ?

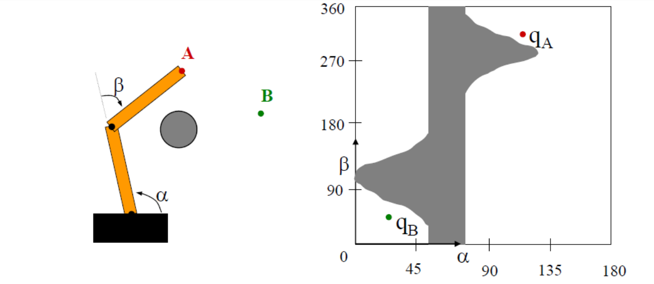
Configuration space, work space and task space



The **workspace** is a specification of the configurations that the end-effector of the robot can reach.

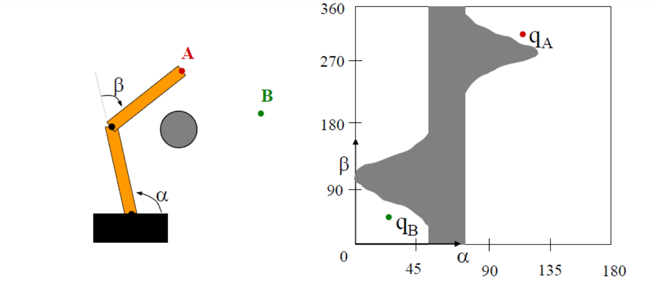
Here, the **workspace** is defined by the (x,y) coordinates of the robot that are specified in the same coordinate system of the world it's manipulating (left image).

Configuration space, work space and task space



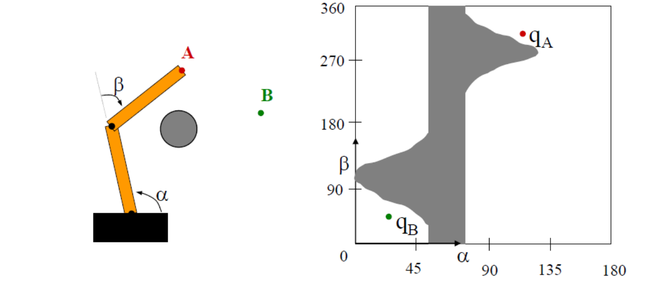
- Although the motion planning problem is defined in the actual world, it lives in another space: the **configuration space**.
- The configuration space (C-space) $\mathcal{C}$ is the n-dimensional space containing all possible configurations of the robot.
- The configuration of a robot is represented by a point in its C-space.
- Here, the C-space is defined by α and β and is represented in the right figure.

Configuration space, work space and task space



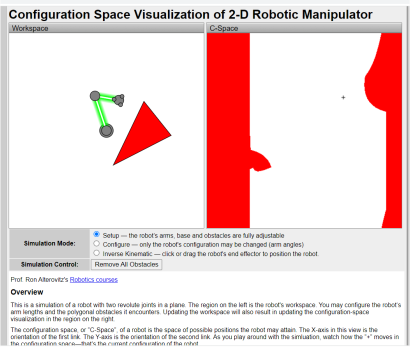
- The definition of the workspace is primarily driven by the robot's structure, independently of the task.
- The **task space** is a space in which the robot's task can be naturally expressed.
- For example, if the robot's task is to plot with a pen on a piece of paper, the task space would be R^2.
- The decision of how to define the task space is driven by the task, independently of the robot.

Configuration space, work space and task space



- Both the task space and the workspace involve a choice by the user.
- For example: the user may decide that some freedoms of the end-effector (e.g., its orientation) do not need to be represented.
- A point in the task space or the workspace may be achievable by more than one robot configuration.
- How do we map the workspace coordinates into configuration space? This is a problem of **inverse kinematics**.

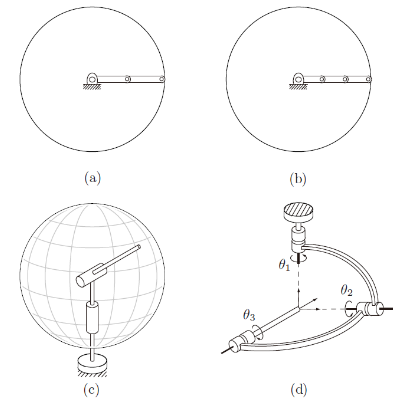
Configuration space, work space and task space



https://www.cs.unc.edu/~jeffi/c-space/robot.xhtml

https://www.youtube.com/watch?v=SBFwgR4K1Gk

Configuration space, work space and task space



- Two mechanisms with different C-spaces may have the same workspace (e.g. a & b)
- Two mechanisms with the same C-space may also have different workspaces (e.g. a & c).

Summary

Summary:

- We covered basic models for decision-making in robotics
- We examined the components of a robot

What next ?

- Cover the basic reactive approaches to robotic control
- Understand motion planning