# Localization and mapping

## From EKF to SLAM

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# Roadmap

1. The perception problem

2. The mapping problem

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2. The mapping problem

To be able to operate autonomously, a robot must continuously answer the following questions:

- **Where am I?**
- **What is this place?**

Thus, it must be able to **perceive** the environment, gathering information useful to:

- **localize itself**, *i.e.*, continuously estimate its **pose** as **both position and orientation** in 3D space;
- **map the environment**, *i.e.*, build a **representation** of the environment useful to **navigate** within it.

# The perception problem

## Challenges

The perception problem is challenging because:

- the environment may be **partially observable**, *i.e.*, the robot can only perceive a **subset** of it, and need to update its information in real time;
- the environment may be **dynamic**, *i.e.*, it can change over time;
- measurements are always subject to **noise**.

The perception problem is usually solved by **sensor fusion**, *i.e.*, combining information from **multiple sensors** to obtain a more **accurate** and **reliable** estimate of the environment, possibly accounting for **sensor faults**.

The tools that robots use to gather **measurements** from the environment are called **sensors**.

They can be classified as:

- **proprioceptive**, *i.e.*, measuring robotic interaction with the environment (*e.g.*, **encoders**, **GPS**, **IMUs**);
- **exteroceptive**, *i.e.*, measuring the environment itself (*e.g.*, **cameras**, **LiDARs**, **radars**);
- **interoceptive**, *i.e.*, measuring the robot's internal state.

As any other measurement tool, sensors are based on **physical principles** and **energy exchanges**, translating the information they gather into **electrical signals** that can be acquired and/or processed by a computer.

They are usually characterized by at least:

- a **digital** or **analog encoding** of the measurement;
- a **frame of reference** in which the measurement is expressed;
- **accuracy** and **uncertainty** parameters.

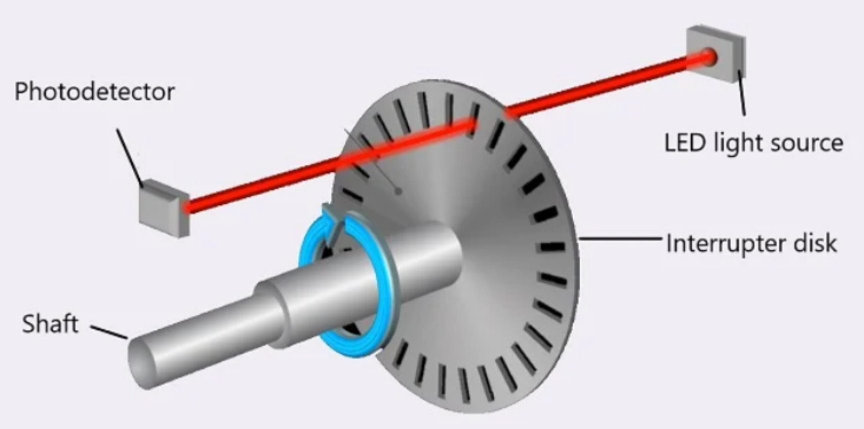


Figure 1: Rotary encoder working principle.

# The perception problem
## Tools for the job

Figure 2: GPS module for drones.

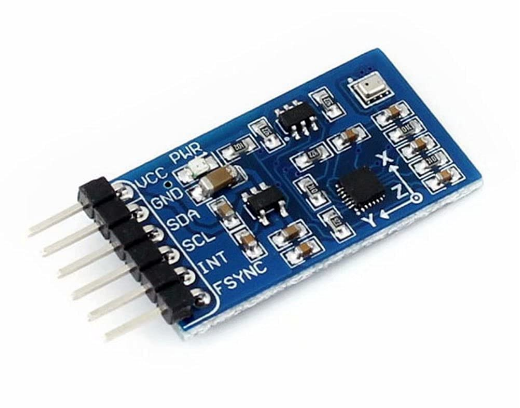


Figure 3: Inertial Measurement Unit (IMU).

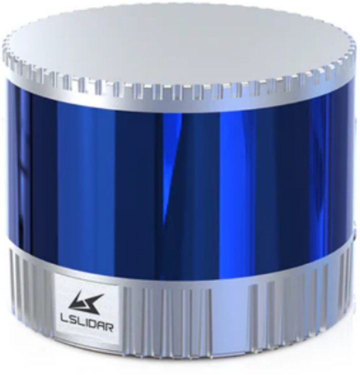


Figure 4: Light Detection and Ranging (LiDAR) sensor.


Figure 5: ZED 2i stereo camera.

# Roadmap

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# The mapping problem

## Definition

Using **exteroceptive sensors**, a robot can gather information about the environment, which can be used to build a **map** of it.

A **map** is a **representation** of the environment, in a format that the robot can **understand**, **parse**, and **store**.

The utimate goal of mapping is twofold:

- to enable the robot to **localize itself** within the environment;
- to enable **safe navigation** of the robot within the environment.

# The mapping problem
## Challenges

Given the utility requirement of a map, the mapping problem must be **continuously solved in real time**.

Thus, it is challenging because:

- routines must be **efficient**, and run at a sufficiently **high rate**;
- the map must be **accurate**, and **reliable**;
- the map must be in a format that is as much **easy to load and parse** as possible, taking up as little **memory** as possible;
- the map must stay **up-to-date**, and **consistent** with the environment.

The most important tool for the mapping problem is the **occupancy grid**, a representation of the environment as a **grid** of **cells**, each of which is **occupied** or **free**.

The occupancy grid is a **probabilistic** representation, where each cell is associated with a **probability** of being occupied or free.

The occupancy grid is usually built using **LiDAR** or **camera** depth data, and is updated in real time as the robot moves.

The occupancy grid is the most common representation for **local** and **global** maps.

To efficiently store an occupancy grid, **tree-like data structures** are often employed (*e.g.*, **octrees**).

# The mapping problem

## Tools for the job

The second most important class of tools are **navigation algorithms**, which use the map to plan a **safe** and **efficient** path for the robot to follow.

The definition of such algorithms involves **geometry**, as well as **optimization** and **search** techniques.

They usually rely on two mathematical subjects:

- **topology**, to define the **connectivity** of the map (*e.g.*, Voronoi tessellation);
- **graph theory**, to define the **best way** of moving from one free cell to another (*e.g.*, Dijkstra's, $A^\star$ algorithms).

# The mapping problem

## Tools for the job

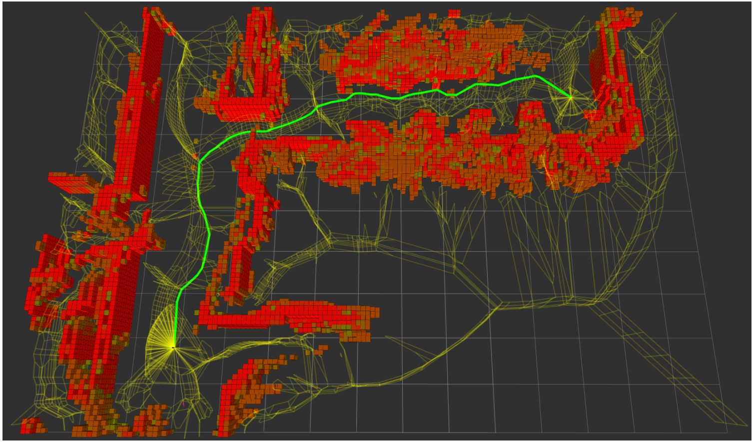

Figure 6: Mapping and navigation algorithms execution.