

Introduction to Robotics

Inteligencia Artificial en los Sistemas de Control Autónomo
Máster en Ciencia y Tecnología desde el Espacio

Departamento de Automática

Objectives

- Introduce main topics on Robotics

Bibliography

No suitable bibliography

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- Perception
- Localization
- Mapping
- SLAM (Simultaneous Localization and Mapping)

Introduction

Introduction to Robotics (I)

Robot definition

Active, artificial agent whose environment is the physical world

Russell and Norvig

- Active: It is not a rock
- Artificial: It is not an animal
- Physical world: It is not just software



Introduction

Introduction to Robotics (II)

Robotics also includes

- Robotic swarms (Video)
- Human-robot interfaces (Video), human-machine interfaces (Video), ...

Fields related to Robotics

- Mechanical engineering
- Electronics
- Artificial vision (Video)
- Machine Learning (Video)
- Learning (Video)
- Neural Networks (Video)
- Evolutionary Computation (Video)

Introduction

Introduction to Robotics (III)

Robots may be **autonomous** or **teleoperated**

- Greyscale between them
- We are interested in autonomous robots

Real-world is demanding

- **Inaccessible**, the world is incompletely perceived by sensors
- **Non-deterministic**, the robot must deal with uncertainty
- **Non-episodic**, the effects of an action change over time
- **Dynamic**, the robot may need to deliberate or to act
- **Continuous**, enumerating all the potential actions is inviable

Introduction

Applications

- Manufacturing and materials handling
- Surveillance robots
- Hazardous environments
- Telepresence and virtual reality
- Augmentation of human abilities
- Prostheses
- Space exploration
- Autonomous cars
- Security and defense

Introduction

Robot categories

Three big categories

- **Manipulators**
- **Mobile robots**
- **Humanoids**

This classification is not strict

Introduction

Robot categories: Manipulators

Applications

- Manufacturing
- Robotically-assisted surgery
- Space
- Harzadous materials

(Video robotic arm)

(Video production line)



Introduction

Robot categories: Mobile robots

Applications

- Exploration
- Hazardous environments
- Defense and security
- Surveillance
- Telecare

Types: UAVs, UGVs, AUV, quads

(Video UAV)

(Video AUV)

(Video Fukushima)



Introduction

Robot categories: Humanoids

Applications

- Research
- Entertainment
- Telecare

(Video Nao) (Video Atlas) (Video DARPA)
(Video DARPA bonus track)

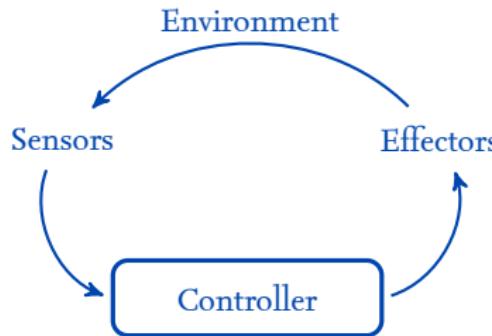


Introduction

Components

Any robot contains three components

- **Effectors** (actuator). Affects the environment
- **Sensors**. Provides knowledge about the environment
- **Controller**. Takes decisions



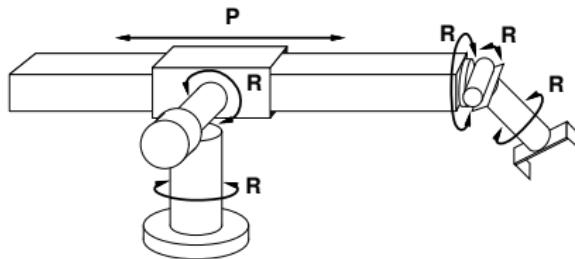
Effectors

Classification

- **Effector:** Device that affects the environment
 - In Robotics, it usually involves motors or hydraulic devices
- Each motion provides a **degree of freedom (DOF)**
- Two ways to use effectors
 - Manipulation: Change the position of other objects
 - Locomotion: Change the position of the robot

Effectors

Manipulation (I)



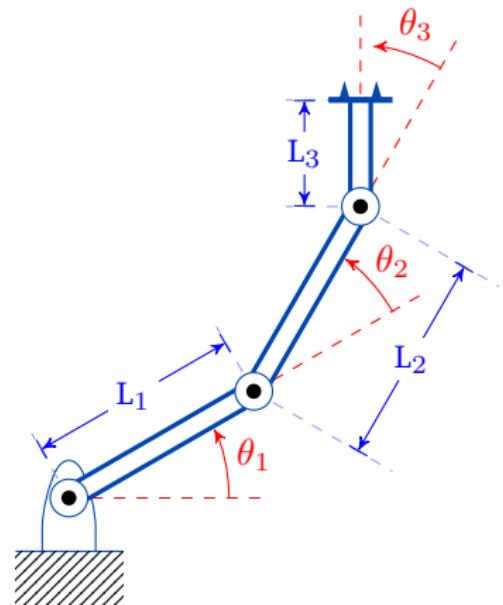
- 6 is the minimum number required to position end-effector arbitrarily
- For dynamical systems, add velocity for each DOF
- **Terminal effector** (or end effector): Tool usually attached to a robotic arm

Effectors

Manipulation (II)

Big issue: Motion planning

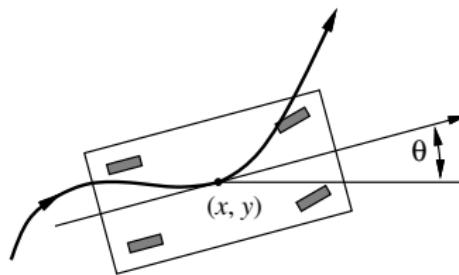
- **Kinematics:** Given the pose, get the location
- **Inverse Kinematics:** Given the location, get the pose



(Source)

Effectors

Locomotion (I)



Two types of mobile robots

- **Holonomic:** Same DOF that control
- **Non-holonomic:** More DOF than controls

Control hardness depends on relation between DOF and control

- The larger is the gap, the harder is the control

Effectors

Locomotion (II)

Types of locomotion



Rover



Walker



Climber



Tracks

Sensors

Classification

Sensor: Device that gathers information

By energy emission:

- Passive
- Active

By function:

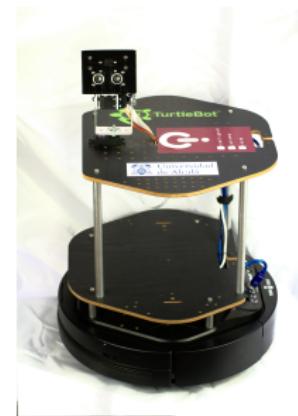
- Range sensors: Sonar, laser scanners, radar, tactile (like bumpers), ...
- Imaging sensors: Cameras (visual or infrared)
- Proprioceptive sensors: Encoders, inertial sensors, force sensors, torque sensors

Sensors

Range sensors: Sonar

Provides a single distance measure

- Uses a sound pulse, usually ultrasound
- Short distance, usually for obstacle detection
- Not very precise
- Cheap (± 2.5 euro)

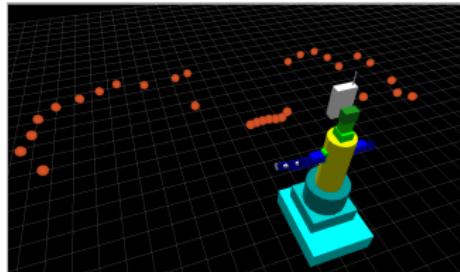


Sensors

Range sensors: Laser scanners

Provides precise ranges

- Several laser beams
- Extremely precise
- 1D, 2D and 3D laser scanners
- Very expensive (thousands)
- Useful for SLAM

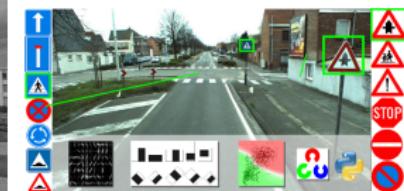
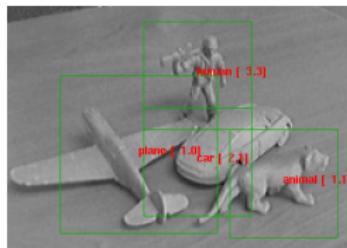


Sensors

Imaging sensors: Cameras

Provides images of the environment

- Different wavelengths (visible or infrared)
- Very important in Robotics
- With proper algorithms, it is almost an universal sensor
- Need of computer vision
 - Object recognition, face recognition, obstacle detection, etc
- From cheap to expensive



Sensors

Imaging sensors: Stereovision

Two parallel cameras

- Information fusion provides depth
- Similar to human vision
- The “poor man” alternative to laser scans
- Quite popular in Robotics



Sensors

Imaging sensors: Depth sensors

Provides image and depth

- Active depth sensor
- Kinect-type sensors
- Increasing popularity in Robotics



Sensors

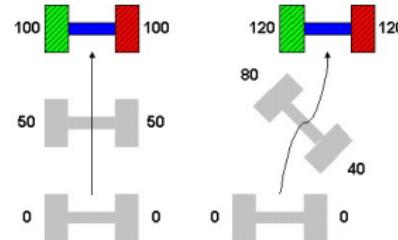
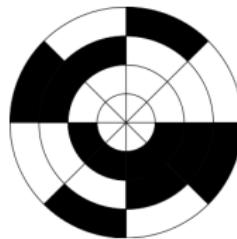
Proprioceptive sensors

Sensors that provide information about the robot state

- Encoders, inertial sensors, force sensors, torque sensors, ...
- Needed for odometry

Odometry: Estimate of change in position over time

- Theoretical position differs from actual position
- Unbalanced motors, power instability, sliding wheels, ...



Navigation

Perception

Mobile robots move around a physical environment

- Perception: Transform *noisy* sensor data into environment models

Perception must satisfy three conditions

- Complete
- Structured
- Reliable

Three problems

- Localization (unknown location)
- Mapping (unknown map)
- SLAM (unknown location and map)

Navigation Localization

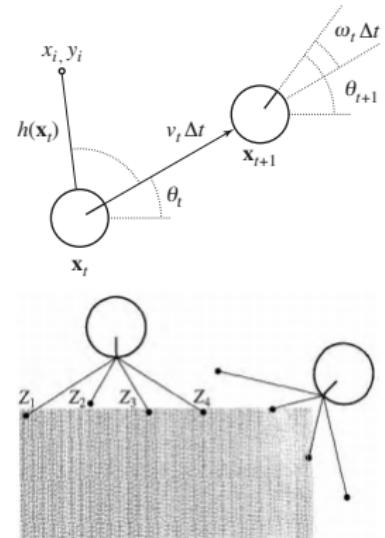
Localization: Where is the robot within the world?

- Unknown location, known map
- Problem: Relate sensor readings to the world

Three problems

- Tracking, initial position known
- Global localization, initial position unknown
- Re-localization, incorrect known position
(kidnapped robot problem)

Beacons: RFID tags, visual marks, QR codes, etc



Navigation

Localization: Monte-Carlo Localization (I)

Monte-Carlo Localization (MCL)

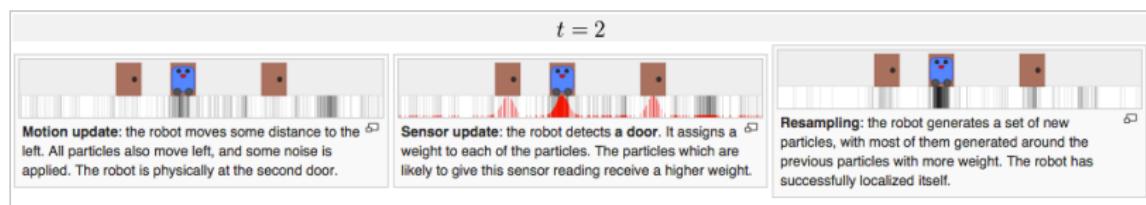
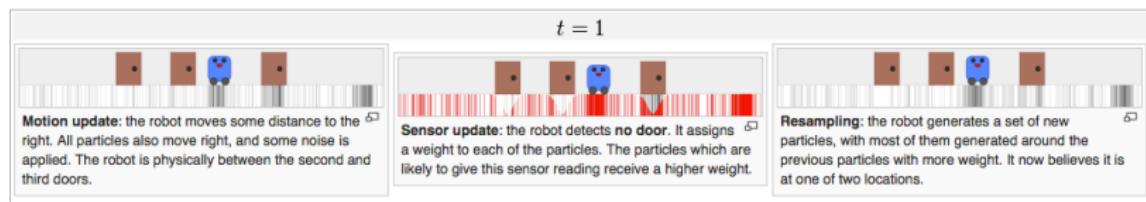
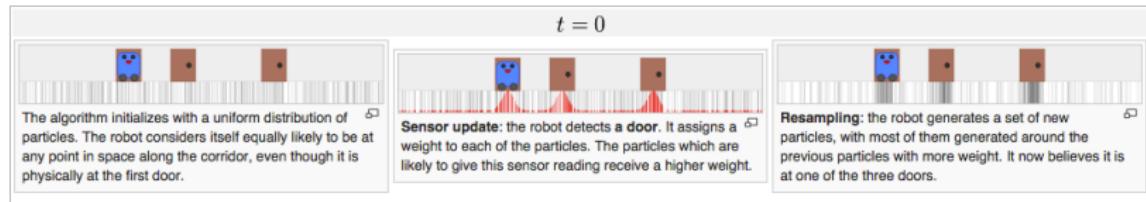
- A type of particle filter
- Estimates robot location and orientation
- Uses a distribution of random particles that converge to robot position
- Prediction of sensor values after motion and compares with measures

(Video particle filter)

(Video)

Navigation

Localization: Monte-Carlo localization (II)



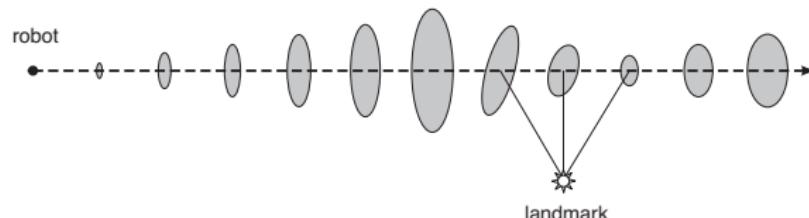
(Source)

Navigation

Localization (III): Kalman filters

Kalman filters (or Extended Kalman Filters, EKF)

- Extended Kalman Filters, or EKF, is a popular extension
- Based on Bayesian Statistics
- Optimal for linear systems with Gaussian noise
 - Otherwise, MCL outperforms EKF
 - Needs less computational resources than MCL
- EKF used for normal operation, MCL used to solve ambiguities



Navigation Mapping

Mapping: How is the world around the robot?

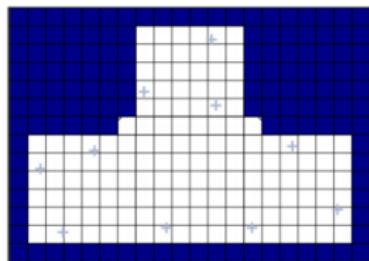
- Known location, unknown map
- Build map

Problem: Integrate sensor measurements to produce a map
(Video Underground Mine Mapping)

Navigation

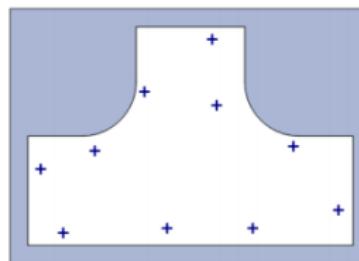
Mapping: Map models

Grid-based



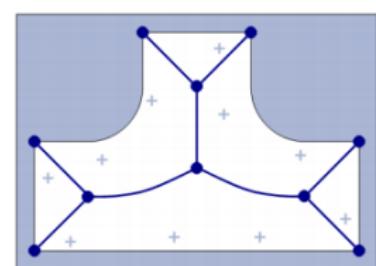
Collection of discretized pixels

Feature-based



Collection of landmark locations

Topological-based



Collection of nodes and links

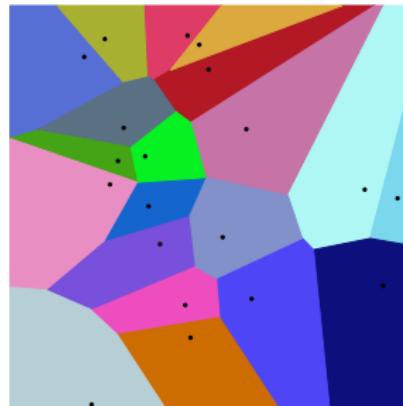
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Navigation

Mapping: Voronoi map

Voronoi diagram: Partition of a plane into regions based on distance points

- Regions boundaries maximize distance to obstacles
- Mapping of boundaries into graphs



(Source)

Navigation

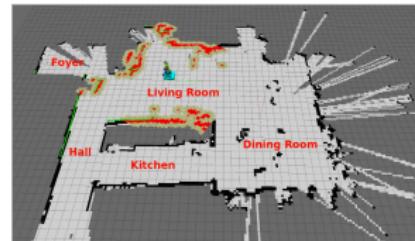
SLAM

SLAM: Map and location are unknown

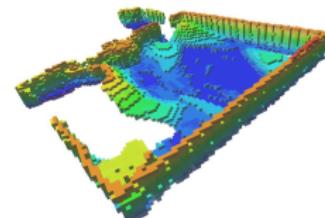
- Big, big problem in Robotics
- Huge number of applications

SLAM techniques

- Extended Kalman filters (EKF)
- Occupancy Grid Mapping



(Video SLAM)



(Video 3D SLAM)