Robotics
Theory

Christian Rossi

Academic Year 2023-2024

Abstract

The course is composed by a set of lectures on autonomous robotics, ranging from the main architectural patterns in mobile robots and autonomous vehicles to the description of sensing and planning algorithms for autonomous navigation. The course outline is:

- Mobile robots' kinematics.
- Sensors and perception.
- Robot localization and map building.
- Simultaneous Localization and Mapping (SLAM).
- Path planning and collision avoidance.
- Robot development via ROS.

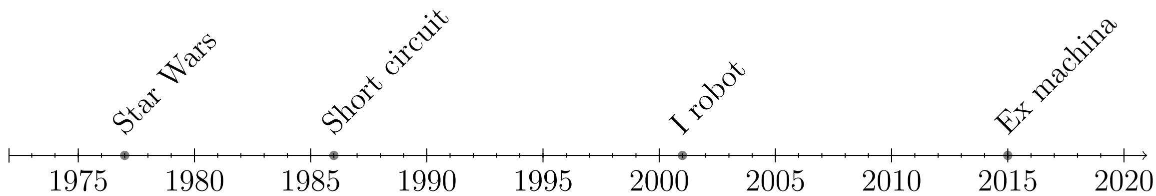
Contents

CHAPTER 1

Introduction

1.1 History

Filmography In the play "Rossum Universal Robots" from 1920, the term "robota" was introduced to refer to the first automatic robots. Several years later, Isaac Asimov penned the renowned science fiction series "I, Robot". Additionally, notable instances of robots in film include:



Robots evolution The mechanical era commenced in 1700 with the advent of the first automata, initially devised as specialized dolls for specific purposes. Transitioning from this era, the dawn of the 1920s saw a resurgence of interest in universal-purpose robots within the realm of fiction.

By 1940, the cybernetics era took root with the creation of the first turtles and telerobots. Grey Walters pioneered a significant development in this era by crafting a robotic tortoise that exhibited mechanical animal tropism (movement directed by stimuli).

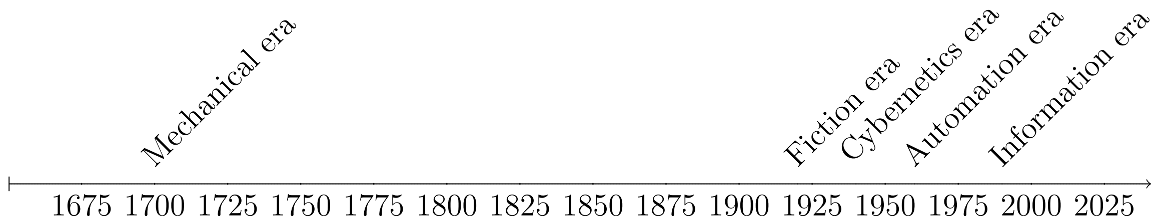
Two decades later, the automation era commenced with the inception of the first industrial robots, marking a shift towards mechanized processes. In 1961, UNIMATE, the inaugural industrial robot, initiated operations at General Motors, executing programmed tasks with precision and efficiency. In 1968, Marvin Minsky introduced the Tentacle Arm, a groundbreaking innovation resembling the movements of an octopus. This hydraulic-powered arm, controlled by a PDP-6 computer, featured twelve flexible joints facilitating maneuverability around obstacles.

In 1972, Shakey pioneered mobility in robotics with the creation of the Stanford cart, heralding advancements in mobile robotics.

The year 1980 witnessed the establishment of the first comprehensive definition of a robot as a reprogrammable, multifunctional manipulator designed for diverse tasks involving material, parts, tools, or specialized devices.

The onset of the information era in 1990 saw robots evolving to possess autonomy, cooperation, and intelligence, marking a significant leap in their capabilities.

Finally, in 2012, the International Organization for Standardization (ISO) established the standard definition for robots, consolidating their diverse functionalities and characteristics into a unified framework.



1.2 ISO definitions

Definition (*Robot*)**.** A robot is an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks. Autonomy in this context means the ability to perform intended tasks based on current state and sensing, without human intervention.

Definition (*Service robot*)**.** A service robot is a robot that performs useful tasks for humans or equipment excluding industrial automation application.

Definition (*Personal service robot*)**.** A personal service robot or a service robot for personal use is a service robot used for a noncommercial task, usually by lay persons.

Examples of personal service robots include domestic servant robots, automated wheelchairs, personal mobility assist robots, and pet exercising robots.

Definition (*Professional service robot*)**.** A professional service robot or a service robot for professional use is a service robot used for a commercial task, usually operated by a properly trained operator.

Examples of professional service robots encompass cleaning robots for public spaces, delivery robots in offices or hospitals, fire-fighting robots, rehabilitation robots, and surgical robots in hospitals. In this context, an operator is an individual designated to initiate, oversee, and terminate the intended operation of a robot or robot system.

Notes A robot system is defined as a system comprising robots, end-effectors, and any machinery, equipment, or sensors that support the robot in performing its tasks.

According to this definition, service robots require a degree of autonomy, which can range from partial autonomy involving human-robot interaction to full autonomy without active human intervention. Human-robot interaction involves information and action exchanges between humans and robots via a user interface to accomplish tasks.

Industrial robots, whether fixed or mobile, can also be considered service robots if they are utilized in non-manufacturing operations. Service robots may or may not feature an arm structure, which is common in industrial robots. Additionally, service robots are often mobile, but this is not always the case.

Some service robots consist of a mobile platform with one or several arms attached, controlled similarly to industrial robot arms. Unlike their industrial counterparts, service robots do not necessarily need to be fully automatic or autonomous. Many of these machines may assist a human user or operate via teleoperation.

1.3 Robot architecture

A machine gathers information from a set of sensors and utilizes this data to autonomously execute tasks by controlling its body parts.

One commonly employed model in robotics is the sense plan act paradigm, which forms the foundation of cognitive robotics. In this model, the sensing phase involves collecting data from sensors, the planning phase utilizes algorithms to process this data, and the action phase involves executing commands through actuators. This architecture is illustrated in the following diagram.

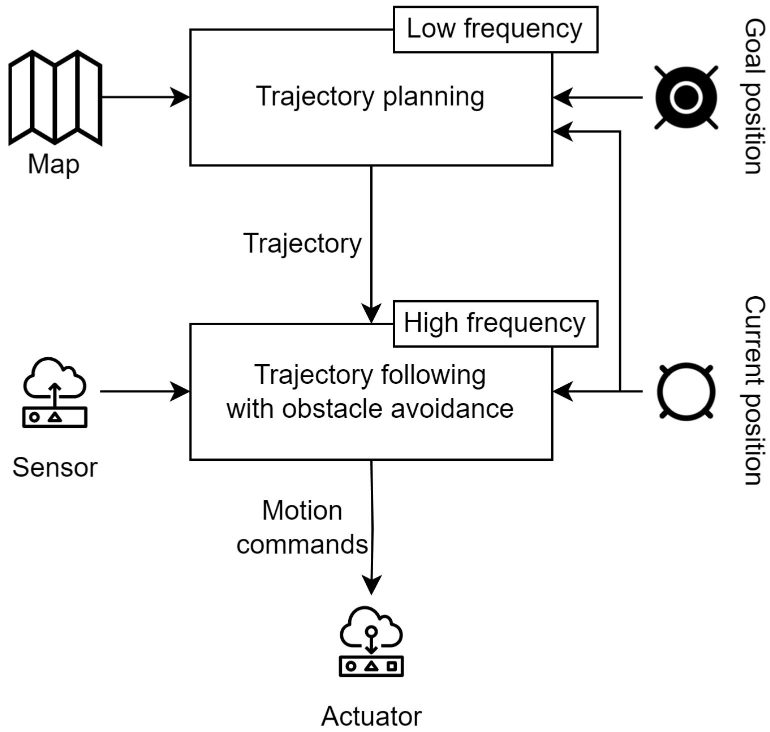


Figure 1.1: Sense plan act architecture

CHAPTER 2

Sensors and actuators

2.1 Introduction

Sensors serve to detect both the internal condition of the robot (proprioceptive sensors) and the external state of the environment (exteroceptive sensors).

Effectors are responsible for altering the state of the environment, with actuators facilitating the actions of effectors.

2.2 Sensors

2.3 Actuators

In robotics, we employ various types of actuators:

- *Electric motors*: these devices convert electrical energy into mechanical energy by leveraging the principles of electromagnetism. They produce rotational motion through the interaction between magnetic fields and electric currents.
- *Hydraulics*: this technology utilizes fluids to transmit force, employing the principles of fluid mechanics to generate, control, and transfer power via pressurized liquids.
- *Pneumatics*: a branch of engineering that employs compressed air or gas to transmit and regulate power, akin to hydraulics but using air or gas instead of liquids.
- *Photo-reactive materials*: these substances undergo a chemical change upon exposure to light.
- *Chemically reactive materials*: substances in this category undergo chemical reactions with other materials or their surroundings.
- *Thermally reactive materials*: these substances undergo changes in properties or behavior when subjected to variations in temperature.
- *Piezoelectric materials*: materials that generate electric charges in response to mechanical stress or pressure, while also displaying mechanical deformation under an electric field.

Originally, early robots were equipped with hydraulic and pneumatic actuators. Hydraulic actuators were costly, heavy, and required significant maintenance, making them suitable mainly for larger robots. Pneumatic actuators found use in stop-to-stop applications like pick-and-place tasks due to their swift actuation.

In modern times, electrical motors have become the prevalent choice for actuators. Typically, each joint incorporates its dedicated motor along with a controller. High-speed motors are often paired with elastic gearing to moderate their speed. These motors necessitate internal sensors for precise control. Stepper motors, on the other hand, don't require internal sensors; however, in case of an error, their exact position becomes unknown.

2.3.1 Direct current motor

Direct Current (DC) motors transform electrical energy into mechanical energy. They are compact, cost-effective, reasonably efficient, and straightforward to operate.

Electric current flows through coils of wire arranged on a rotating shaft. These wire loops create a magnetic field that interacts with the magnetic fields of permanent magnets positioned nearby. The resulting interaction between these magnetic fields causes them to repel each other, resulting in the rotation of the armature.

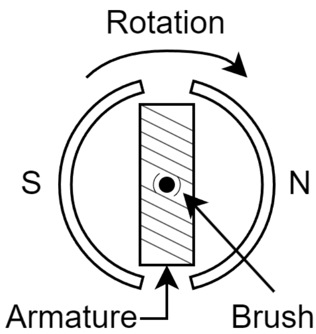


Figure 2.1: Brushed motor structure

Continuously adjusting the current causes the armature to keep rotating and generating motion. This current modification is facilitated by two connectors positioned at the center of the armature, known as brushes. It's worth noting that in lower-cost electrical motors, the external magnets remain stationary. However, these budget-friendly versions encounter several issues related to their brushes:

- Brushes gradually wear out over time.
- Brushes generate noise during operation.
- They impose a maximum speed limit.
- Cooling them proves to be challenging.
- They restrict the number of poles that can be utilized.

To circumvent this issue, one can opt for brushless motors, where external magnets are substituted with copper coils and a magnet is positioned at the center. This configuration yields a motor wherein brushes are replaced by electronics, permanent magnets reside on the rotor, and electromagnets are situated on the stator. While these motors offer superior performance, they also come at a higher cost compared to their brushed counterparts.

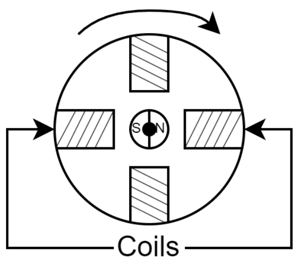


Figure 2.2: Brushless motor structure

2.3.2 Stepper motor

The stepper motor, a type of synchronous electric motor lacking brushes, transforms digital pulses into mechanical shaft rotations.

A stepper motor offers several advantages: it provides a direct correlation between input pulse and rotation angle, maintains full torque even at standstill when windings are energized, enables precise positioning and repeatability, responds promptly to starting, stopping, and reversing commands, boasts high reliability due to the absence of contact brushes, facilitates open-loop control which simplifies and reduces costs, supports very low-speed synchronous rotation with directly coupled loads, and offers a wide range of rotational speeds. However, there are also disadvantages: it necessitates a specialized control circuit, consumes more current compared to DC motors, experiences a reduction in torque at higher speeds, risks resonances if not adequately managed, and finds it challenging to operate at extremely high speeds.

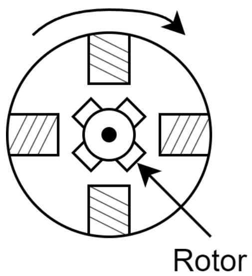


Figure 2.3: Stepper motor structure

The step angle, denoted by φ, can be determined using the following formula:

$$\varphi = \left(\frac{N_s - N_r}{N_s \cdot N_r} \right) \times 360^\circ$$

In this equation, N_s represents the number of teeth on the stator, and N_r represents the number of teeth on the rotor.

2.3.3 Servo motor

A servo is a type of specialized motor designed to precisely move its shaft to a specific position. These motors find common use in hobby radio control applications. They possess the capability to measure their own position and adjust for external loads in accordance with a control signal.

Servo motors are typically constructed from direct current motors with additional components including gear reduction, a position sensor, and control electronics. The travel range of the shaft is usually limited to 180 degrees, which is adequate for the majority of applications.