Lecture 01.04 Robot potency

acting A robot must be able to *act* on its environment. Common acts are in service of locomotion and manipulation, but there many others, like cleaning (e.g. vacuuming), cutting (e.g. CNC milling), and delivering material (e.g. 3D printing).

As is often the case when deepening our understanding of a device, following the flow of energy through it, a robot in this case, will help us better understand it. We start with where the robot gets its energy and follow this through its application to the environment in an action, as shown in Figure 01.5.

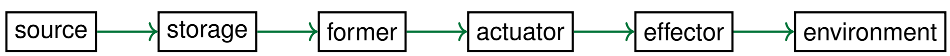

Figure 01.5: power flow through a robot.

01.04.1 Energy, its source and storage

Actions require energy, which is typically delivered on-demand from the electrical grid for stationary robots (typically manipulation arms) and delivered from an on-board battery for mobile robots. Some mobile robots can harvest energy (e.g. via solar panels), but the rate of harvest is typically much slower than is required for peak performance. Therefore, mobile **battery** robots tend to have energy limitations and *battery* technology is crucial for mobile robot development.

Box 01.1 self-driving cars and batteries

Self-driving cars are typically electric and rely on large, rechargeable batteries, typically of the lithium-ion variety. Considerations here include energy storage capacity (vehicle range), power rating (vehicle power), recharge rate (driver waiting for recharge), self-discharge rate (when chilling), specific energy (J/kg), and lifespan.

01.04.2 Electrical power forming

Before a robot applies power to the environment, it must first first transform it into the appropriate form for its actuators (considered next). The two **DC** **AC** primary forms of electrical power are *direct current* (DC) and *alternating* *current* (AC). Batteries delivers DC power and the grid delivers AC. Some actuators take DC and others AC power.

In mobile robots, due to a reliance on (DC) battery power and the efficiency cost of *DC-to-AC* conversion, DC actuators are preferred. In stationary robots, like those for manipulation, AC power is plentiful, so both AC actuators and DC actuators (using *AC-to-DC* conversion) are used.

DC-to-AC **AC-to-DC**

Further sub-forms of DC and AC power can also be identified, as outlined in Figure 01.6. These sub-forms come about because most of the time actuators will need to be delivered variable quantities of power. For instance, *switched DC* power or *pulse-width modulation* (PWM) can be used to deliver variable average power to an actuator: by rapidly switching DC power on and off, the actuator average power is varied. This digital electronics technique is usually less expensive than the analog *amplifiers* required for truly continuously varying DC power. A drawback of switched power is that it introduces significant high-frequency noise, which can negatively impact sensors.

switched DC **PWM** **amplifiers**

AC power also has sub-forms. Some high-power AC actuators require multiple *phases*, frequently three. In this case, three different signals with proper phase differences must be delivered. Other AC actuators operate at one steady-state speed per *frequency* of AC power. For changing speeds, this frequency must be varied—something achievable with a *variable-frequency drive*.

phases **VFD**

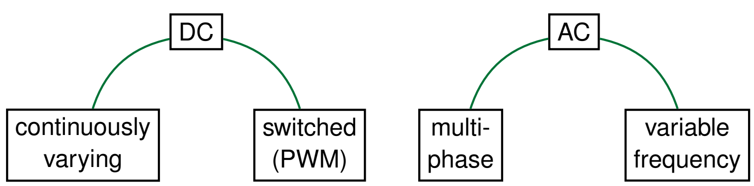

Figure 01.6: forms of electrical power for actuation.

01.04.3 Actuation

actuation

Actuation is a robot's transduction of electrical power to the proper energy domain for its corresponding effector (considered next). Usually, this device is *electromechanical*. In fact, the paradigmatic actuator is the *motor* in its 31 flavors.

electromechanical **motor**

Most motors convert electrical power to *rotational* mechanical power, but some, called *linear motors*, convert to *translational* power. The fundamental mechanism in a motor is the *Lorentz force* acting on a wire sur-

linear motors **Lorentz force**

rounded by a magnetic field and through which electrical current is flowing. The varieties of motors are essentially different methods of arranging for this mechanism's unfolding.

The following list describes some types of motors important for robotics.

DC motors are those that require DC power in its various forms (e.g. switched).

- **BDC** or brushed DC motors have a mechanical contact that reverses current flow. These are inexpensive but are less efficient than other types and require more maintenance due to brush wearing.
  - **PMDC** or permanent-magnet DC motors are brushed and have a background magnetic field generated by permanent magnets. These are relatively easy to model, but require feedback to control.
  - **Wound-stator** DC motors are brushed and have a background magnetic field provided by an electromagnetic coil.
- **BLDC** or brushless DC motors are actually AC motors with complex built-in electronics that allow it to act like a DC motor. These are more-expensive and require expensive electronic controllers, but require less maintenance than BDC motors.
- **Stepper** motors are DC motors that (usually) rotate a predictable amount for each DC pulse applied. The "usually" qualifier here means that for accurate position control, feedback is still required. These are fine for some position control, but are not great for continuous rotation or high speeds.

AC motors are those that require AC power in its various forms (e.g. multiphase).

- **Induction/asynchronous** AC motors generate a rotating electromagnetic field that induces current to flow through an electrical loop in the rotor (the part that spins with the shaft). Again, the Lorentz force kicks in. In steady-state, there's a difference called
slip *slip* between the rotation rate of the electromagnetic field and that of the rotor. The speed of these motors is varied by changing the frequency of the AC power with a VFD. These are very common for large-load industrial applications.
- **Synchronous** AC motors generate a rotating magnetic field on both the stator (the part that doesn't turn) via electromagnetic coils

and on the rotor via either permanent magnets or DC electromagnets. Since they do not rely on magnetic induction, the rotor field and stator have the same angular velocity in steady-state (i.e. there's no slip). If the rotor uses an electromagnet, brushes are required, with all their baggage. These can be more expensive than induction motors, but they can be also be driven by a VFD.

Another term frequently encountered here is *servomotors*, which has two common meanings. The first is simply most any of the motors above[2] of suitable quality for precise feedback control. The second is really a package: a motor, a speed measurement device (usually an *encoder*), and a *feedback controller*. Sometimes the controller is included and other times it is sold separately.

servomotors

encoder

feedback controller

Since the desired effect of the actuator on the effector is frequently not simply rotation in the range of speed and torque of the motor, *mechanisms* frequently comprise the final stage of the actuator. This is the stuff of mechanical engineers' dreams: gears, spools, pulleys, linkages, belts, tracks, power screws, etc.

mechanisms

01.04.4 Affection

It also means "to affect"—the robot's environment in this case! Most of the time, this is a mechanical interaction. And *interaction* it is: let's not forget Newton's third law here; the robot's structure and, if applicable, base, will experience reaction forces.

Devices actuators use to yield effects in the environment are called *effectors*,[3] which have direct interaction with the environment. Common effectors include pretty much all the locomotion devices considered previously and grippers, claws, feet, wipers, water jets, high-power lasers, sanding pads, and suction cups.

effectors

[2] A possible exception here is a stepper servomotor.

[3] Affect is usually a verb and effect usually a noun, so you might be offended by the term "effector." However, effect *can* be a verb. I looked it up.

Example 01.04-1 power flow through a solar rover bot

Consider a solar-powered rover bot for exploring the surface of Mars, illustrated below (PR). For the behaviors of (a) driving and (b) collecting a soil sample with an arm, trace the flow of power through the robot, and along the way identify energy storage elements, energy transducers, actuators, and effectors.