Lecture 01.02 Robot mechanicality

For a device to be considered a robot, it must have a mechanical presence in an environment. One immediate conclusion from this is that a *simulation* is not a robot. This does not mean we cannot simulate robots. In fact, we *must* simulate a robot to design one of any value, which is part of why we spend several chapters on just that, later in this text.

simulation

So what does it mean that a simulation is not a robot? There are two points here being emphasized.

1. Reality is much more complicated than can be simulated, and therefore even good robot simulations cannot account for everything. Reality's tough, kid!
2. Simulations of robots are great, but they can do no mechanical work.

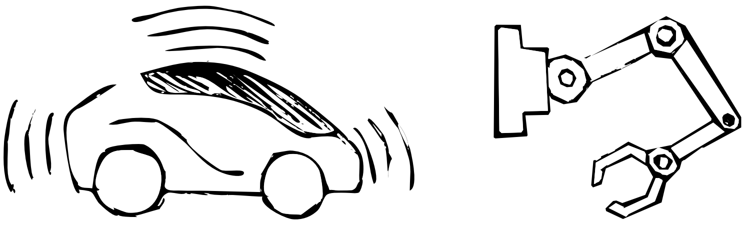
Or, put simply: a simulation doth not a robot make.

Another implication of the mechanicality of a robot is that it has *space* and therefore *matter* and *form*. What is the stuff (matter) of a robot? Most robots are made of the usual materials found in machines: metals, plastics, rubbers, and ceramics. And, of course, silocon. The form one takes depends on its function. A robot that must change its location requires a means of *locomotion*. One that must manipulate objects in the world must change its own *orientation* relative to the world.

space
matter
form
locomotion
orientation

These last two are more than simple examples. They divide the two primary types of robots: *mobile robots* and *manipulation robots*. The paradigmatic case of the former is the *self-driving car* and of the latter is the manufacturing *robot arm*. There's no reason a self-driving car can't have a robot arm (can't be both a mobile and a manipulation robot), but that's just showing off.

mobile robots
manipulation robots
self-driving car
robot arm



(a) self-driving car (b) robot arm

Figure 01.1: examples of two types of robot, (a) mobile and (b) manipulation. (PR)

01.02.1 Locomotion

locomotion

Mobile robots must do something basic to animal life: move about in an environment. Moving about, or *locomotion*, is a fascinating topic with novelty everywhere. Something that makes it challenging is that it depends on both the robot and its environment. For instance, a robot that locomotes with wheels might not be effective at navigating the terrain of a rocky hillside, and a lake even less-so.

Locomotion, then is a robot-environment problem. Some types of environments commonly considered are: on-ground (i.e. terrestrial), underground (i.e. fossorial), in-liquid (e.g. aqueous), in-gas (e.g. aerial), and space. Most robots effectively move about in only one of these. Usually, there is enough variation in each type of environment (e.g. calm versus stormy air) to render robots effective in just a subset of the types of environment listed above.

locomotion methods

Examples of *methods of locomotion* include:
• rolling • walking • jumping • stick-slipping • slithering • undulating • jet-propelling • rotary-propelling • flapping • gliding • soaring • swimming • ballooning.

locomotion devices

Examples of robotic *locomotion devices* include:
• wheels • tracks • legs • arms • tails • rockets • propellers • sails • wings • fins • magnets • cilia.

biomimicry

Locomotion is one of the fields of robotics that relies most heavily on *biomimicry*. Animals have developed incredible and unique methods of locomotion, and the study of them has been a gold mine for robotics.

actuators
effectors
behaviors

It is worth considering here a three-fold distinction made among *actuators*, *effectors*, and *behaviors*. Consider the aerial robot of Figure 01.2 that flies by flapping its wings. The motor actuates the wings (effectors) which produces the behavior of flapping or flying.

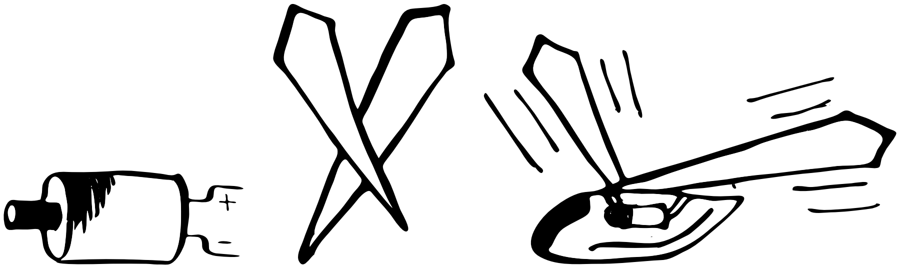
navigation

location
orientation
mechanics

This brings us to another important consideration in mobile robotics, *navigation*. This involves several of the qualities of a robot we'll consider in the text, but the mechanical facet of navigation is that of describing spatial *location* and *orientation* through time, and the forces involved. We'll return to these considerations, which constitute the study of *mechanics*, at the end of this lecture.

01.02.2 Manipulation

Manipulation robots move around objects in the world. Although it is not a requirement, most of the time they are themselves stationary, attached to



(a) actuator: motor (b) effector: wings (c) behavior: flapping or flying

Figure 01.2: example of how actuators, effectors, and behaviors are related. (PR)

something relatively fixed. This helps the robot move things by providing "somewhere to stand," as it were.

Manipulation robots also use actuators, effectors, and exhibit behaviors. The behavior of *grasping* is especially important for manipulation robots: by grasping an object (typically with an effector called a "gripper"), it becomes rigidly attached to the effector, the position and orientation of which is presumably known to the robot, and the robot can then manipulate the object by changing its own position and orientation.

grasping

It's hard to think a manipulation robot without an arm, a fact that jives with a survey of primates, animals known for cognition and an ability to manipulate tools. This does not mean there aren't superior ways, but that arms are, dare I say, close at hand to a human designer.

Let's consider another way of understanding the advantages of an arm for a manipulation robot. The concept of *degrees of freedom* (DOF) will help us here. Later we will consider the world's three-dimensional space in greater detail, but for now consider that an object in this space can potentially *translate* in three independent directions and *rotate* about three independent axes. Speaking a somewhat simplified mode, we can say that a robot has a degree of freedom for each independent axis along with it can translate and about which it can rotate. Returning, then, to the arm, we see it has several *joints* that allow it to increase its DOF. The jointedness of arms are the key to their excellence in manipulation: the more degrees of freedom it has to move, the more complex can its movements be.

DOF

translate
rotate

joints

There are systematic ways of classifying joints and arms in terms of DOF, which we will later consider. For now, we simply want to understand the motivation of going into a detailed analysis. The goal of analyzing joints and arms is to describe an arm's position and orientation, how to make it move from one to another, and understanding the forces there-involved. As in the conclusion of the preceding section on locomotion, we have found ourselves concerned with matters of *mechanics*.

mechanics

01.02.3 Mechanics

force

Mechanics is the study of the motion of matter and the causes and effects thereof. We call the cause of motion *force*, which is typically understood to potentially produce the motion of matter. As mechanical engineers, we are interested in several sub-fields of mechanics, including fluid mechanics, solid mechanics, and rigid-body mechanics. Most of these specialized fields of study are focused on the motion and forces that cause it in specific types of material.

kinematics

kinetics

It is convenient to differentiate between two primary considerations in mechanics: *kinematics*, which mathematically describes the motion of matter and *kinetics*, which mathematically describes the forces that cause motion.

inverse kinematics

A famously challenging aspect of mechanics in robotics is called *inverse kinematics*, which is the study of how to "back out" the positions and orientations of a robot's parts that yield some desirable overall configuration. The quintessential example here is a robot arm: if we want the gripper to be located in a certain position and orientation, where should each of the individual joints be?

There are frequently *multiple* solutions for a given gripper configuration. This problem is exacerbated by the fact that frequently there are additional constraints on variables, yielding a system of equations and inequalities. Even worse, these equations are usually *nonlinear*. Good analytic and numerical techniques for inverse kinematics have been developed, and we will consider some later in the text.