**Definitions**

A robot is …

A programmable, multifunction manipulator designed to move material, parts, tools, or specific devices through variable programmed motions for the performance of a variety of tasks.

A [non-living] physical agent that performs tasks by manipulating the physical world.

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**Categories of robots**

Manipulators
- Physically anchored to workplace
  - For example, industrial robotic arms

Mobile robots
- Move about their environment using wheels, legs, or similar mechanisms
  - For example, autonomous vehicles

Hybrids
- Mobile robots with manipulators
  - For example, humanoids

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**What are robots good for?**

**Manufacturing**
- Repetitive tasks on a production line are natural tasks for automation.
  - 1961 – Unimate developed by Joseph Engelberger and George Devol
    - Sold to GM and used to manufacture TV picture tubes.
    - Devol earlier obtained first US patent on a robot.
  - 1972 – Nissan among the first to automate entire assembly line with robots.

**Transportation**
- Self-steering vehicles (see notes from last lecture).
- Autonomous helicopters and planes that deliver objects to locations that would be dangerous or hard to access by other means.
- Gofers – for example, Helpmate
  - Used in dozens of hospitals.
  - Transports food and other items.

**Hazardous environments**
- Applications include
  - Toxic waste cleanup
  - Deep sea recovery
  - Exploration
- Mining
  - Manipulation of biologically hazardous materials
  - Examples include
    - Robots to clean up and explore after Chernobyl disaster
    - Robots for clearing minefields
    - Robotic fly

Exploration
- Mars rover.
- Dextre – 2-armed robot; part of the Mobile Servicing System on the International Space Station.

Health care
- Nursebot – intended to help guide individuals in assisted living communities.
- Assist with instrument placement when operating on organs as intricate/sensitive as brain, eye, heart. Recent application to prostate surgery.
- Hip replacement.

Personal services
- Vacuum cleaners
- Swimming pool cleaners
- Lawn mowers

Human augmentation
- Devices that make it easier for people to walk or move their arms.
- Some involve teleoperation – i.e., robot manipulator emulates motion of human operator (Dextre, for example)
- Brain-Computer Interfaces (robotic wheelchair, for example)

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### Robot parts

- Effectors
- Sensors

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### Effectors

An effector is any device that affects the environment, under the control of the robot.
- Will make use of an actuator
  - Converts software commands into physical motion
  - Motor or hydraulic cylinder, for example

Used in two main ways
- Locomotion
- Manipulation

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### Locomotion

Various types, including snake-like slithering, but most commonly....
Legged locomotion [Videos]
- Useful for motion in rough terrain with large obstacles.
- Include hopping robots
  - Dynamically stable
    - Will crash if forced to pause
    - Do well as long as they keep moving
  - Use rhythmic motion of four legs, two legs, or even a single leg to control locomotion

Wheel, tread robots
- Most practical for most environments
- Simpler to build, more efficient, and provide better static support
- But with issues of their own:

Example. Car
- Three degrees of freedom – two for its (x,y) position and one for direction it’s pointing.
- Only two actuators (driving and steering) – for small motions, car has two degrees of freedom (can’t move sideways).

Nonholonomic robot – has fewer controllable degrees of freedom than total degrees of freedom.

A general rule – the larger the gap between controllable and total degrees of freedom, the harder it is to control the robot.

Possible to build truly holonomic robots, but at the cost of mechanical complexity.

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**Manipulation**

Rotary motion – rotation around a fixed hub.
Prismatic motion – linear movement, as with a piston inside a cylinder.

A free body in space has six degrees of freedom
So manipulator needs six degrees of freedom => six joints.

We count one degree of freedom for each independent direction in which a robot (or one of its effectors) can move.

[How many degrees of freedom in the human hand?]

End effector interacts directly with the world
- Screwdriver or other tool
- Welding gun
Paint sprayer
Gripper (manufacturing applications typically make use of two- or three-fingered grippers)
Anthropomorphic hand

Sensors: Tools for Perception

One way to categorize sensors based on how they gather information:
- Passive sensors
  - True observers of the environment
  - e.g., cameras
- Active Sensors
  - Send energy into the environment
  - e.g., sonar

Passive vs Active Sensors
- Active sensors tend to provide more focused information, but at the cost of increased power consumption
- Danger of interference when multiple active sensors are used

Another way to categorize sensors

Based on what they record:
- Sensors that record distances
- Sensors that record entire images
- Sensors that record information about the robot itself

Range Finders

Sonar
- Sound Navigation and Ranging
  - Emits sound waves which are reflected by objects; reflected sound gets back to the sensor; time and intensity of signal carry information about distance
  - Alternatives include radar and laser
  - Provides useful information about objects fairly close to the robot
  - Very effective for obstacle avoidance and tracking a nearby object
  - Generally won’t provide precise data for mapping
    - Not a narrow beam of sound – conical spread
    - Sound only received back from patches of surface that are at right angles to the beam
GPS
- Measures the distance to satellites that emit pulsed signals
- Can determine absolute location on earth to within a few meters
- Does not work indoors or under water

**Close range sensors**

Include whiskers, bump panels, and

Touch sensitive skin
- Consider the task of picking up a paper cup
- Robotic version of the human sense of touch
- Uses an elastic material and a sensing scheme that measures the distortion of the material under contact
- Sensor may give data at an array of points on the elastic surface
- Like an image of “deformation”
- Can also sense vibration

**Image sensors**

For example, cameras. While the general problem of computer vision is hard, techniques exist for making visual interpretation more practical

- If the robot’s set of tasks is limited, vision need only supply information relevant to those tasks
- Can modify the environment to make the robot’s task easier
- Can include bar-code stickers in various locations to get exact position fix (for example, in environment of a robotic wheelchair)

**Proprioceptive sensors**

- Give a robot a sense of itself – i.e., its own position, orientation, etc.
- Encoders fitted to the joints can provide very accurate data about joint angle or extension
  - If the output of an encoder is fed back to the control mechanism during motion, the robot can have much greater positioning accuracy than humans
  - Typically a few thousandths of an inch of accuracy in its end-effector position
  - Humans can manage only a centimeter or two

- Change in position can be measured using odometry
  - Based on sensors that measure wheel rotation, for example
  - Position error an issue – due to slippage of wheels
- Magnetic compass or gyroscope system often used to measure orientation reliably

Why is it so hard to build robots?

The real world is:

- Inaccessible – sensors are imperfect and can only perceive stimuli that are near the agent.
- Nondeterministic – you never know if an action is going to work; wheels slip, batteries run down, etc.
- Nonepisodic – the effects of an action may change over time.
- Dynamic – robot needs to know when it’s worth deliberating and when it’s better to act immediately.
- Continuous – states and actions are drawn from a continuum of physical configurations and motions.

[DARPA Grand Challenge video]