CSCI 4961/6961 Advanced robotics, Spring 2000
Course notes — ROUGH DRAFT!!!

Systems & components of mobile robots

The objective of this section is to convey a basic understanding of the systems and components of a mobile robot — not in so much detail that you'd be able to go and build a robot right away, but at least enough to give you a perspective on what is involved and some of the issues and design tradeoffs that would arise.

Mobile robots are often designed to operate in human environments. However, the basic capabilities of robots and humans are quite different. This results in many instances where some compromise must be made in the design.

1 Locomotion

The two basic choices for mobile robot locomotion are legs and wheels. Legged locomotion is well suited for rough terrain, whereas wheeled locomotion is best suited for terrain that is not too steep and doesn't require driving over obstacles that are too big. Here I'll focus on wheeled locomotion.

There are three main aspects of a wheeled locomotion system: the configuration, the motors, and the mechanics (wheels, tires, gears, etc.).

1.1 Wheeled locomotion configuration

There are 6 basic configurations for wheeled locomotion:

- *tricycle steering* The front wheel drives the vehicle and can be steered. The back wheels are passive. Disadvantages include the more limited stability of a three wheeled platform and more complex mechanism for driving and steering the same wheel.
- *Ackermann steering* The back wheels drive the robot (through a differential). The front wheels are passive drive but steer the robot. An Ackermann linkage steers the front wheels so that the robot can move about a single rotation center. Advantages include better stability and that the driving and steering of the vehicle are separated. Disadvantages are increased mechanical complexity in the Ackermann linkage and the differential for the real wheels.
- *differential drive* Two coaxial wheels are independently driven. One or two casters provides stability to the platform. Advantages include the simplicity of the mechanism; the need for casters is a disadvantage.
- *skid steer* Typical skid steer platforms use tank treads on the left and right sides, though some platforms use multiple wheels on each side (typically 3 on each side that are all driven by the same motor). In order to turn, some wheel (or part of the tank treads) must skid on the ground. Skid steering is well suited for outdoor terrain, but makes control and dead reckoning difficult.
- *synchro drive* Three or more wheels are mechanically coupled so that they all point in the same direction. One motor controls the wheel direction; another drives all the wheels. This platform is easy to maneuver because it can move in any direction.

- *all wheel steer* Each wheel is independently steered and driven. Although this requires a lot of motors and mechanical complexity, this provides the most control over the robot movement.

1.2 Mechanics

The previous section alluded to *dead reckoning*; this refers to a procedure which repeatedly updates the current position based upon traveling a certain distance at some heading. This practice dates back to its use in sailing, probably to the emergence of the magnetic compass around 1100–1300 AD. Errors in dead reckoning accumulate, so it is not suitable for navagation by itself. We can correct errors in dead reckoning though the use of landmarks.

Still, dead reckoning (sometimes equated with odometry) is important feedback for a mobile robot, and there are several factors in the mechanics of the locomation system which affect the accuracy of dead reckoning.

In order to get odometry for a mobile robot, we must measure how much the wheels turn. This is often accomplished by using some sort of encoder (such as an optical or magnetic encoder).

Wheel slip is the most notorious cause of error in dead reckoning. If the wheels slip on the ground, then a robot will think it traveled further than it actually did. Sometimes this occurs because there is not enough friction between the tires and the ground. It may also be due (among other reasons) to traveling over rough terrain (bumps or cracks).

For purposes of reducing wheel slip, wheels should be as narrow as possible. When turning sharp corners, the left and right edge of a wide wheel should travel at different velocities; instead there is a little bit of wheel slip.

The tires on a wheel serve to provide traction on the ground; they also serve as part of the (or sometimes as the entire) suspension which is responsible for providing a smooth ride, i.e. isolating the body of the robot from the terrain roughness.

Tires deform where they contact the ground. This provides some of the suspension of the robot, but it also changes the effective diameter of the wheel which must be known when computing dead reckoning.

Some robotics researchers reflect that dead reckoning is pretty good when going straight, but turns introduce significant dead reckoning error. Another issue that affects dead reckoning is the backlash in motor gearing. Whenever two gears mesh, there is a small abount of "play" so that the gears can turn and so they don't grind against each other. If the gear reduction is high (as it often is for DC motors), there must be several stages of gears, and the backlash accumulates. A wheel could be subject to several degrees of backlash which could introduce significant dead reckoning error in turns.

1.3 Motors

- basic model of a motor

  A loop of wire in a magnetic field. Force on a current carrying wire is $F = l\vec{I} \times \vec{B}$. EMF generated on a wire in a moving conductor is $E = \vec{v} \times \vec{B}$. One loop of wire produces a $|\sin\theta|$ torque waveform. Using several loops at different angular offsets leads to a (more or less) constant torque, i.e. $T = K_t I$ where K_t is the torque constant. The variation in torque is called torque ripple.

  Electrical model of a motor is $V = IR + L\frac{dI}{dt} + e$ where $e = K_e\omega$ is the back-EMF. We'll assume that the inductance is small, so we get $V = IR + K_e\omega$

- torque vs. speed

  Substitute $T = K_t I$ in the above and you get: $\omega = \frac{-R}{K^2}T + \frac{V}{K}$. (The two constants are the same.) Graph this line in Torque vs. speed. The x intercept is the stall torque. The y intercept is the no load speed.

- power output $P = Tw$

- efficiency $P_{in} = IV = I(IR + K\omega) = \frac{R}{K^2}T^2 + \omega T$

2 Sensors

We will focus on sensing for navigation. This may include simply detecting obstacles for avoidance or may be for recognizing landmarks. We may only need/want rough information on where an object/obstacle is located, or we may want a more detailed model of it.

- vision — clearly the most informative source of information for people, but we only know how to extract limited information from computer vision. This also places a great hardware, power, and computation demand upon a robot.

- laser rangefinders — a scanning laser rangefinder measures the time light takes to reach an object and reflect back, producing a depth map of the scene in front of the robot. Scanning laser rangefinders are expensive but provide accurate data.

  Simpler laser rangefinding systems project a plane of laser light ahead of a robot and view the scene with a video camera whose lens has a filter to only see the laser light. By triangulation, you can compute what lies ahead (on the laser light plane).

- SONAR — measures the time an ultrasonic pulse takes to bounce off obstacles and return to the sensor. Cheap and easy to use, but the data are noisy. There can be problems with echos and “multi-path”. Effective range of approximately 1 foot to 30+ feet for models that come on indoor mobile robots. Objects may not show up in a sonar scan if they are too narrow. Beam width is a problem as are the side lobes of the ultrasonic transducer.

  Sound travels at roughly 345 m/s (speed is sensitive to temperature, humidity, etc.)

- IR — an infrared emitter shines light and a detector tells whether any is reflected back. Typically used for short range obstacle detection. Not entirely reliable as the return can depend upon the surface color/material and the angle of incidence. Some newer sensors use rudimentary triangulation which avoids some of these problems.

- bump sensors — just a switch that is closed when the robot runs into something, these are often used on robots as a backup in case other sensors fail.

3 Computing

- microcontroller versus a real computer

- I/O

4 Communication

- IR — line of sight only
- RF
  - single channel, multiple channel
  - packet transceivers
  - wireless ethernet

5 Power

When designing a robot, keep in mind both the average and the peak power required by your components when formulating your power budget. Batteries are the most common power source for robots; they are cheap and most are rechargeable. Batteries are rated in Ampere-hours (which is a measure of power). A 1 A-h battery can provide 1 Ampere of current for 1 hour, or 250 mA of current for 4 hours.

There are many different types of batteries, with tradeoffs in cost, energy density, and recharging requirements.

- lead acid — no memory effect, low energy density (slightly less than 40 WHr/Kg)
- nickel cadmium (NiCad) and nickel hydride (NiMH) — common, memory effect. NiCad batteries have an energy density of just over 40 WHr/Kg.
- lithium (just over 100 WHr/Kg)

Power conditioning: power must be regulated to drive elecronics! Often separate power systems are used to drive the motors and the electronics to avoid noise/interference.