CS 460/560
Introduction to Computational Robotics
Fall 2019, Rutgers University

Lecture 04
Sensor Mechanisms

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Outline

Common sensors

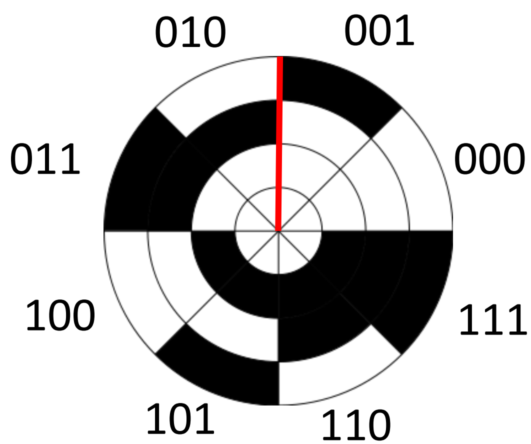
- ⇨Encoders
- ⇨Heading/orientation
- ⇨Acceleration
- ⇨Inertial measurement unit (IMU)
- ⇨Range sensors
- ⇨Motion/speed sensors
- ⇨Vision

Modeling sensors

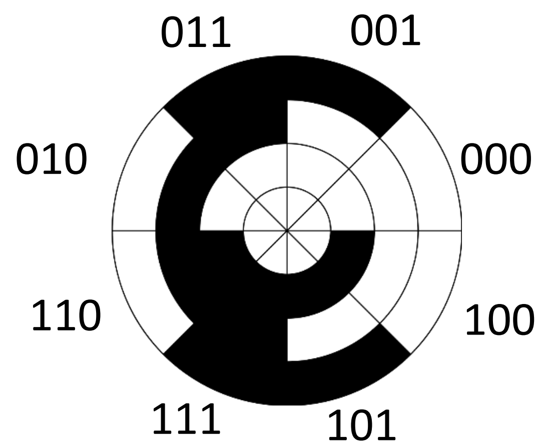
Encoders, Absolute

Wheel encoders measure position and rotation speed

Absolute (standard binary vs **Gray code**)



Standard binary encoder

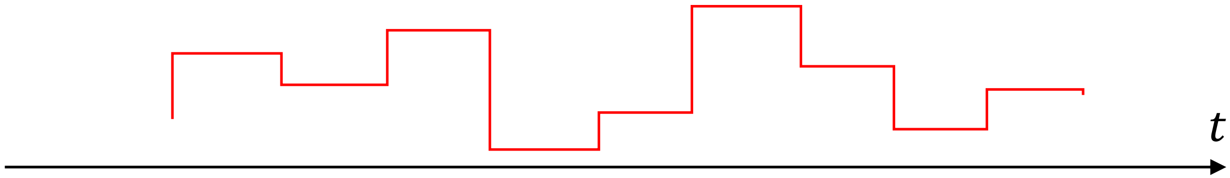


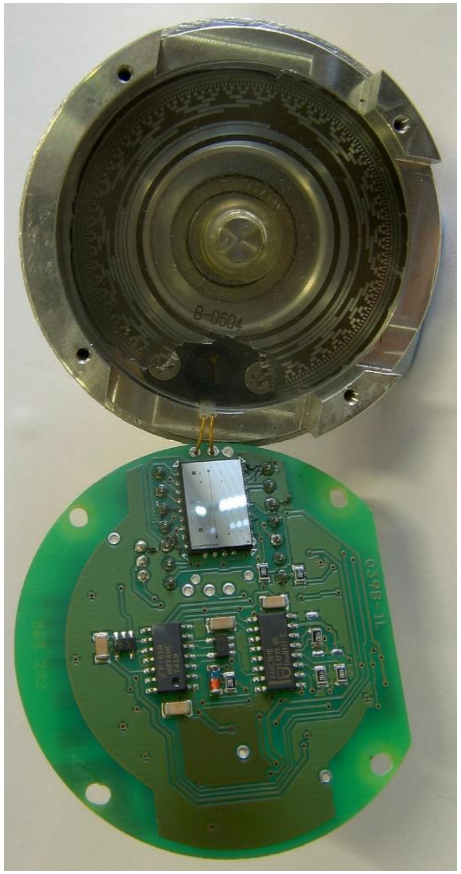
Gray code

⇨Measure exact (quantized) wheel position

⇨Do not need to track time for position

⇨With time, can also measure speed



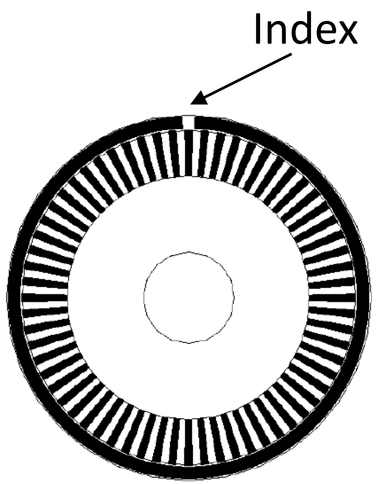


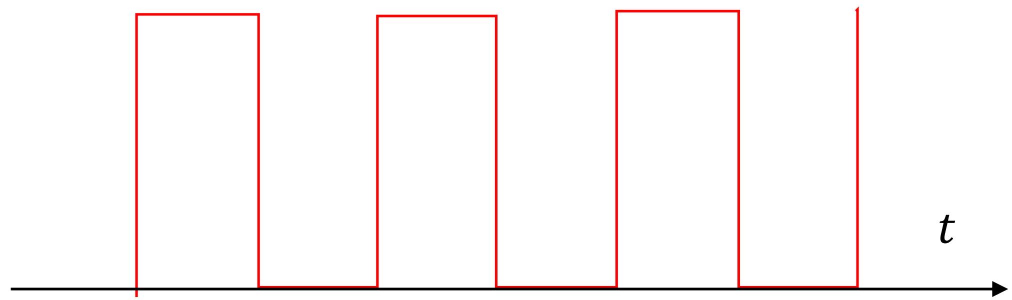
13 track Gray code absolute rotary encoder

Images from wikipedia

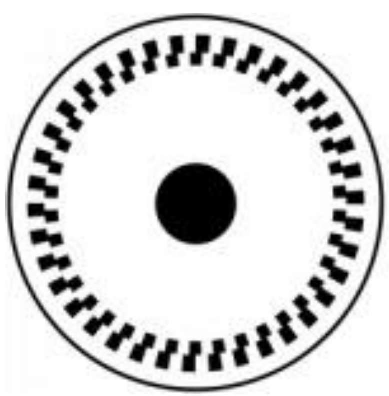
Encoders, Relative

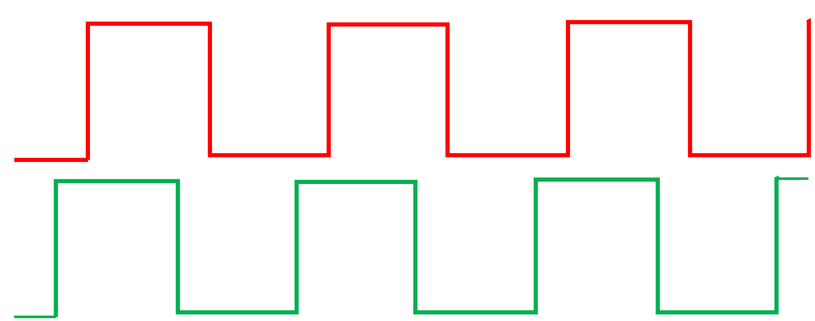
Relative





- ⇨Relative: mainly direction/speed, not absolute angle
- ⇨A single set of gaps may have difficulty determining direction
- ⇨Can add an offset set of gaps to address this
- ⇨Offset by ¼, forward and backward become asymmetric





Images from IMTR, www.phidgets.com/docs21/Encoder_Primer

Encoders, Applications

Encoders are very useful in robotics

- ⇨ For figuring out wheel states
- ⇨ For figuring out positions of robotic arms
  - ⇨ E.g., Universal Robots UR5 arm
  - ⇨ Can be highly accurate!
  - ⇨ For UR5, the repeatability is ± 0.1 mm or ± 0.0039 in

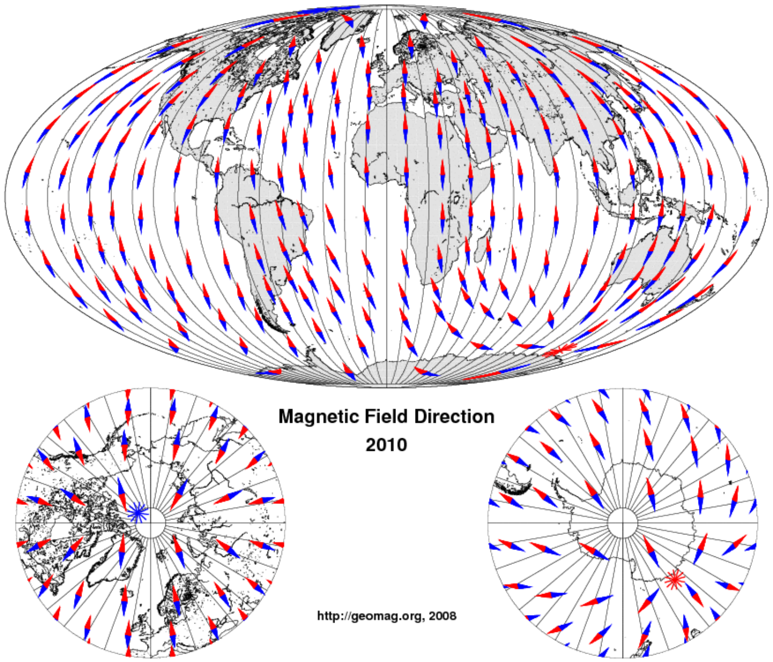
Orientation Sensors

Generally, there are two types of orientation sensors

- ⇨2D: $SE(2) = \mathbb{R}^2 \times S^1$, single orientation on S^1
- ⇨3D: $SE(3) = \mathbb{R}^3 \times SO(3)$, three orientations, e.g., $(yaw, pitch, roll)$

Two-dimensional orientation sensor

- ⇨Compasses!
- ⇨They don't always work reliably
  - ⇨ Globally, magnetic field changes over time
  - ⇨ Locally
    - ⇨ Natural magnetic objects
    - ⇨ Man made magnetic/electro-magnetic fields



Magnetic field direction image from geomag.org/info/declination.html

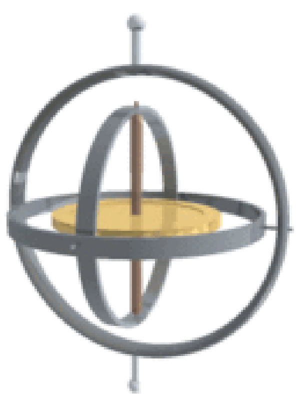
Orientation Sensors, Continued

Gyroscopes (three-dimensional orientation sensors)

- ⇨Operational principle: angular momentum (inertia)
  - ⇨ A spinning wheel "likes" to stay the way it is
- ⇨A **gimbal** is a device allowing free rotation along one axis
- ⇨A gyro is a wheel mounted on 2+ **gimbals**
- ⇨Used in many equipment, e.g., aircraft
- ⇨Can be non-mechanical

A toy "gyro"

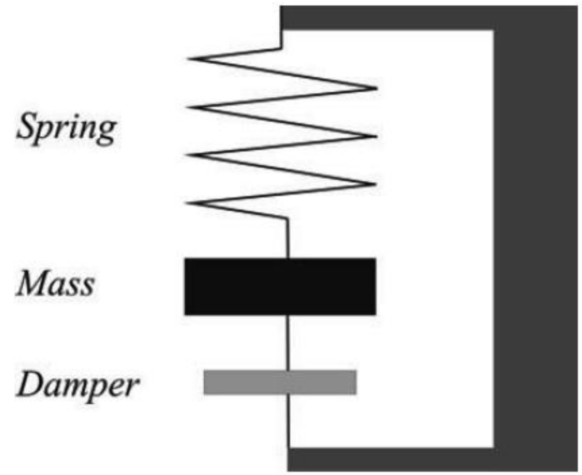
Gimbal camera mount



3-gimbal gyro

Gyroscope image from wikipedia

Acceleration Sensor



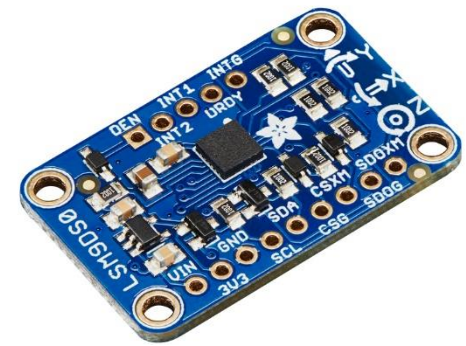
Accelerometers

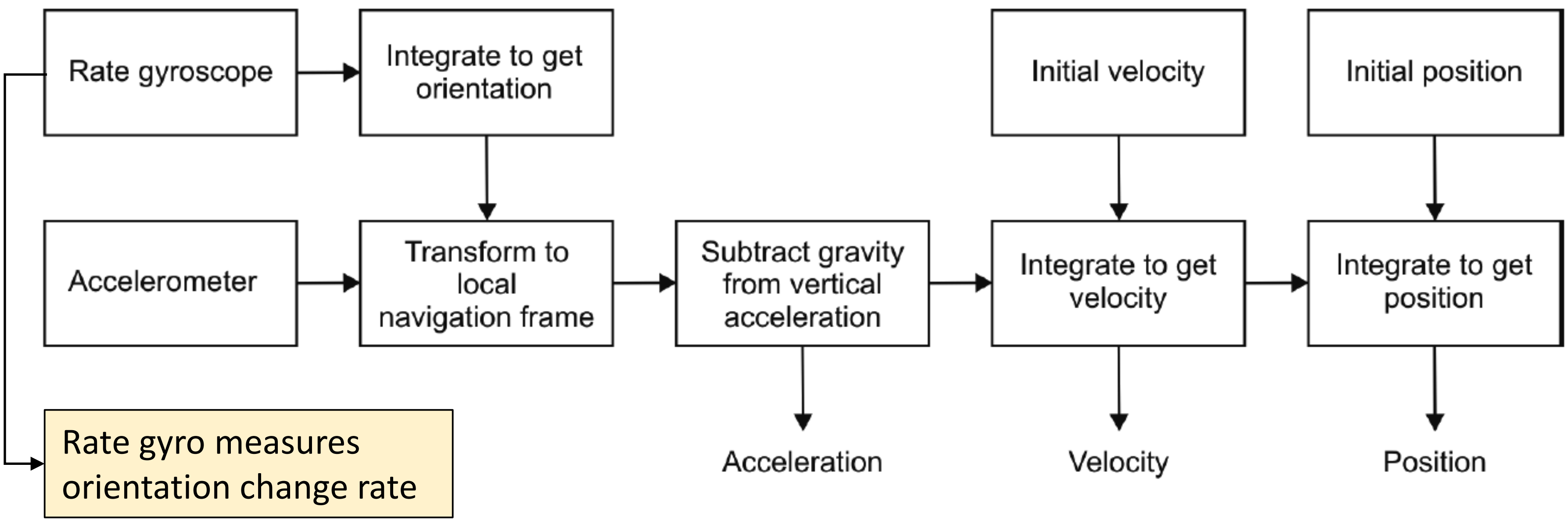
- ⇨Also based on inertia (linear momentum)
  - ⇨ Newton’s first law
- ⇨A mass tends to keep its current momentum
  - ⇨ Changing it requires force
  - ⇨ $F = ma = kx$ (Newton’s second law)
- ⇨Measures a single direction, e.g. x
  - ⇨ For three dimensions, need three such mechanisms
  - ⇨ Can be done with a single mass though
- ⇨A useful trick for figuring out where the “ground” is
  - ⇨ Earth has gravity, which is an acceleration force
  - ⇨ Actually very large and fixed magnitude, often dominates other forces
  - ⇨ Provides us with a “ground” direction
- ⇨Accelerometers can be made very small!
- ⇨May replace spring with piezoelectric mechanism

Inertial Measurement Unit (IMU)

IMU uses both angular and linear inertial effects

- ⇨How?
- ⇨Gyro + accelerometer
- ⇨Produces 3D position, velocity, acceleration
- ⇨Pipeline
- ⇨IMUs may also have magnetic and other sensors





Range Sensors

Time-of-flight ranging

- ⇨Measure distance by measuring time traveled (by sound or light)

$$distance = speed \cdot travel\ time$$

- ⇨Light travels much faster
  - ⇨ Accurate, but more difficult to measure
- ⇨Sound is slower, but works in water well
- ⇨Many things to consider
  - ⇨ Time measurement
  - ⇨ Speed variance (esp. sound)
  - ⇨ Signal uniformity (e.g., sound cone)
  - ⇨ …

Sonar

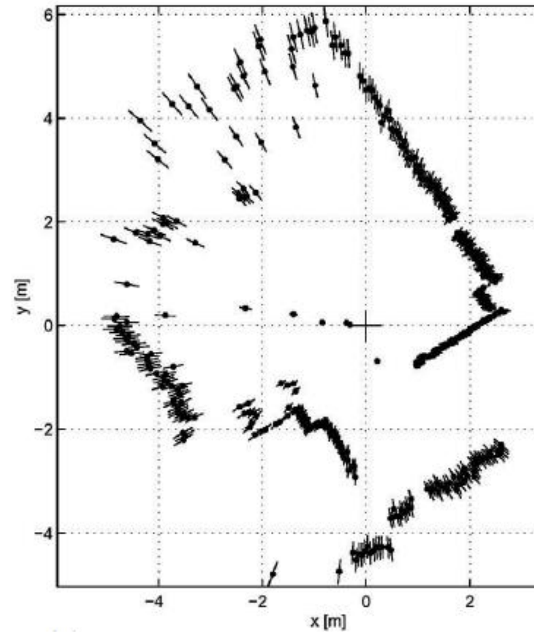
Triangulation (will cover this later)

Phase shift

- ⇨Measure distance by measuring phase of light
  - ⇨ Light is a wave

“Lidar” (often uses triangulation)

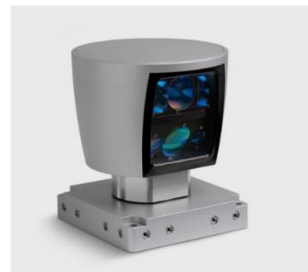
Range Sensors, Continued



Sonars

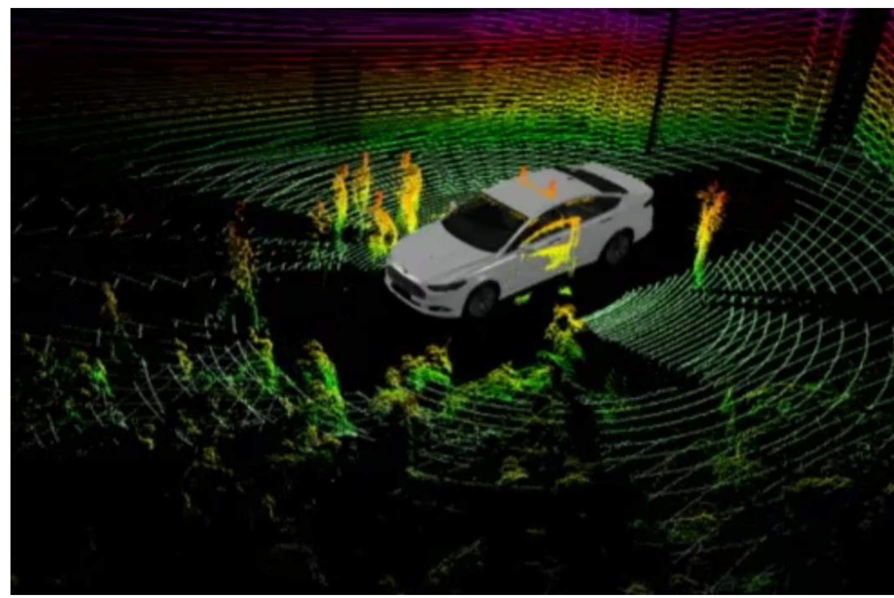
Laser scanners

- ⇨Two dimensional
- ⇨Three dimensional
- ⇨Similar principles

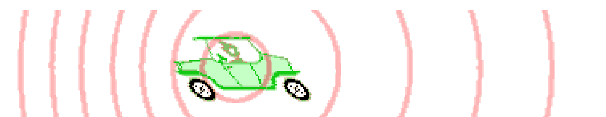


Other (more complex) methods

- ⇨Structured light
  - ⇨ Used in Microsoft Kinect
  - ⇨ iPhone X has something similar
- ⇨See IAMR 4.1



Speed Sensors and Vision Sensors



Speed sensor: Doppler effect

- ⇨Uses wave aspect of sound/light
- ⇨Faster then more frequent arrival
- ⇨Very accurate

Vison sensors

- ⇨You have seen many of these
- ⇨Yes – just cameras
- ⇨But can do 10T FPS now…

Sensor Modeling

A sensor can be modeled using a function h:

$$h: X \to Y$$

X: state space

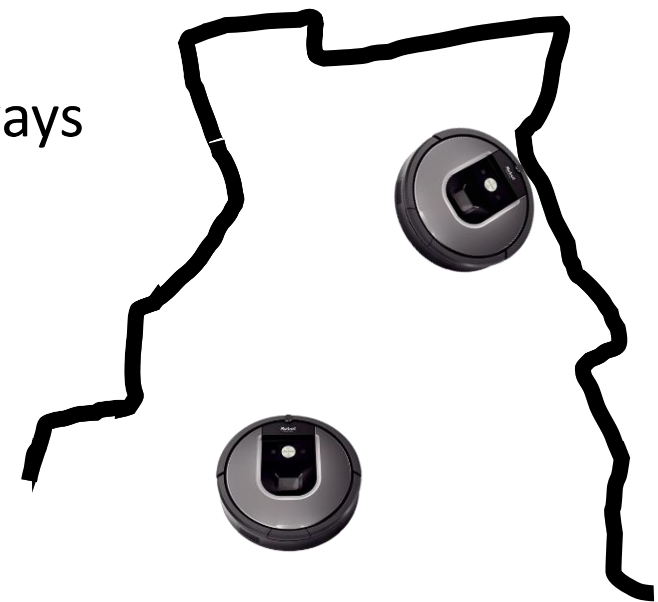
Y: observation space

h: sensor (mapping) function

Often, X and Y may be the same; but not always

Examples

- ⇨Position sensor: $h: \mathbb{R}^3 \to \mathbb{R}^3$
- ⇨Orientation sensor: $SO(3) \to SO(3)$
- ⇨Contact sensor: $h: SE(2) \to \{0,1\}$



We will not do this very formally in this class