Today

- (A little admin)
- How sensors work conceptually
- What makes for a good sensor
- Examples of a few sensors
- Most importantly, what can you do with them

Sensing

- Receiving information about the robot's physical surroundings

- Sensors must be appropriate for the robot's tasks
- A central theme of Chapter 7 is that you must figure out what it is that your sensors will detect
  - All the more important that you think in terms of functionality

https://github.com/gcl8a/arduino-tutorials

Sensor Classification

- Proprioceptive sensors
  - Measure values internal to the robot
    - *Position of the wheels*
      - *Steering angle*
      - *Rocker-bogie angles*
      - *Wheel shaft angle*
    - *Motor speed*
    - *Motor current*
    - *Robot arm joint angles*
    - *Battery voltage*
    - *Internal temperature*
    - *Fuel remaining*

- Exteroceptive sensors
  - Acquire information from the robot’s environment
    - *Distance measurements*
    - *Light intensity*
    - *Sound amplitude*
    - *Bearing to a sound/light/heat source*
    - *Facial detection, etc.*

Sensor Classification

- Passive sensors
  - Measure ambient environmental energy entering the sensor
  - *Temperature probes, contact switches, microphones, CCD or CMOS image sensors (cameras)*
- Active sensors
  - Emit energy into the environment, then measure the reaction
  - *Ultrasonic sensors, laser rangefinders*
  - Often have superior performance (e.g., color detection)
  - Issues with signal interference

What are some desirable qualities of a sensor?

- That is, what makes one sensor better than another?

What are some desirable qualities of a sensor?

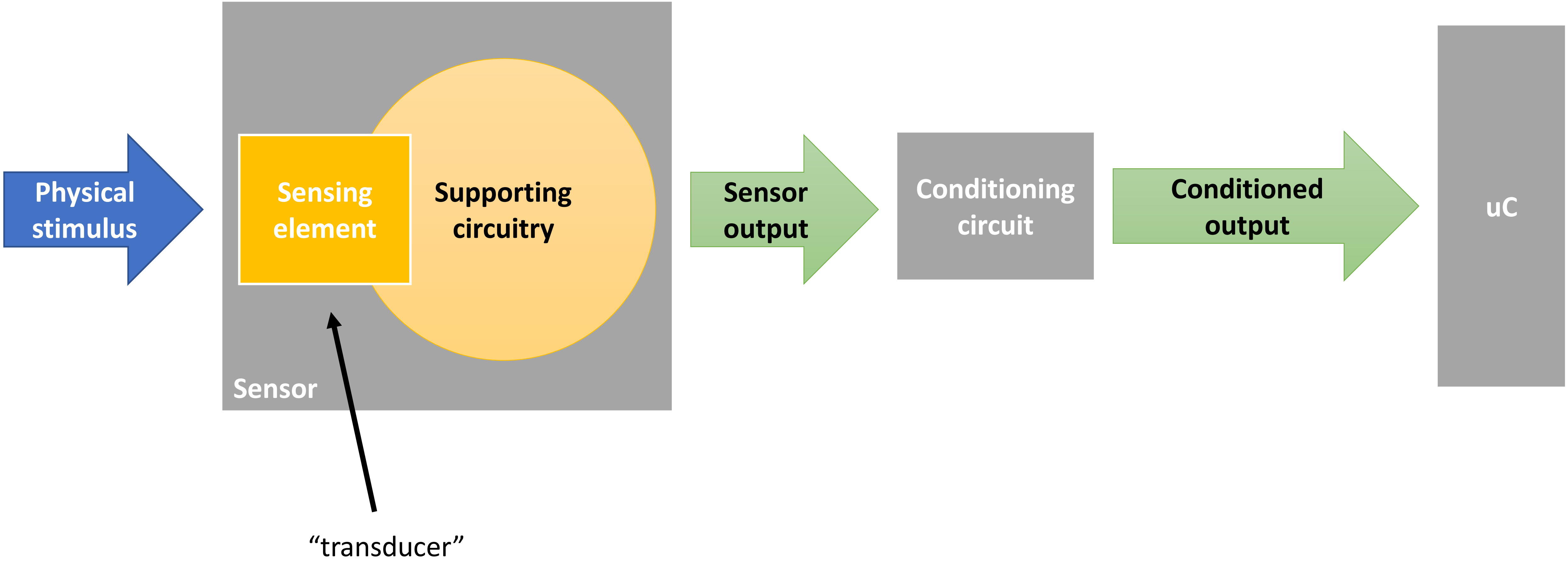
- *Sensitivity* is a representation of how much the output changes for a given change in the input
  - *Resolution* is the smallest change that the sensor can detect
- *Specificity* is how well the sensor detects the signal of interest and removes others
- *Accuracy*
- *Precision*

What are some desirable qualities of a sensor?

- Sensitivity
- Specificity
- Accuracy
- Precision

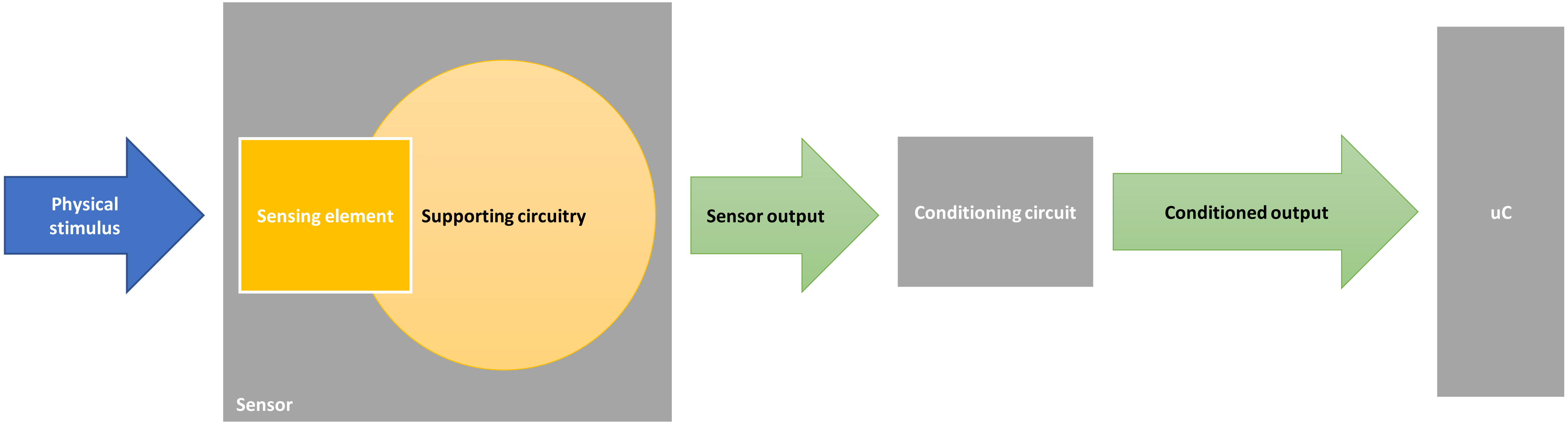
- *Low cost*
- *Simplicity*
- *Availability*

Basic process



Amplification

- Amplification is used to increase the intensity of a signal



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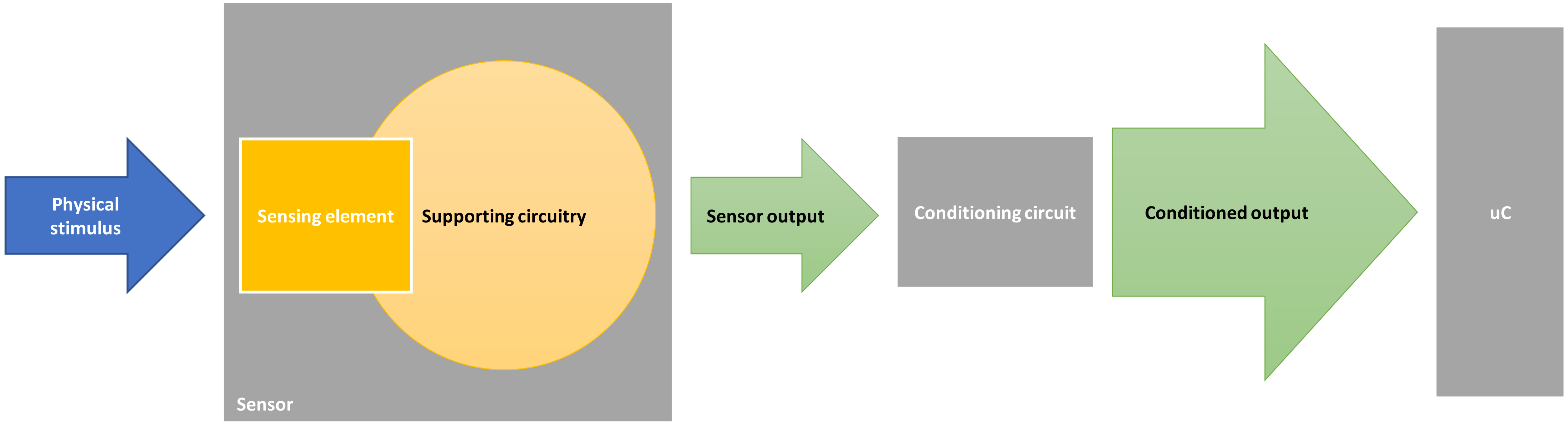
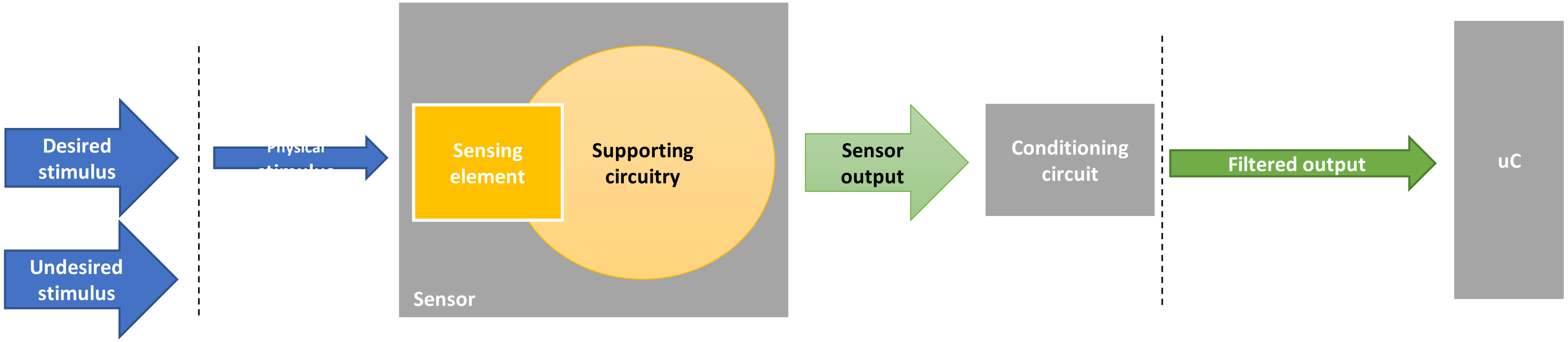


Filtering

- Removing unwanted signals is an important task
  - Physical filters remove unwanted signals before they can affect the sensitive element
  - Electronic filters act on the response of the sensor
  - Numerical (computational) filters are implemented in the microprocessor



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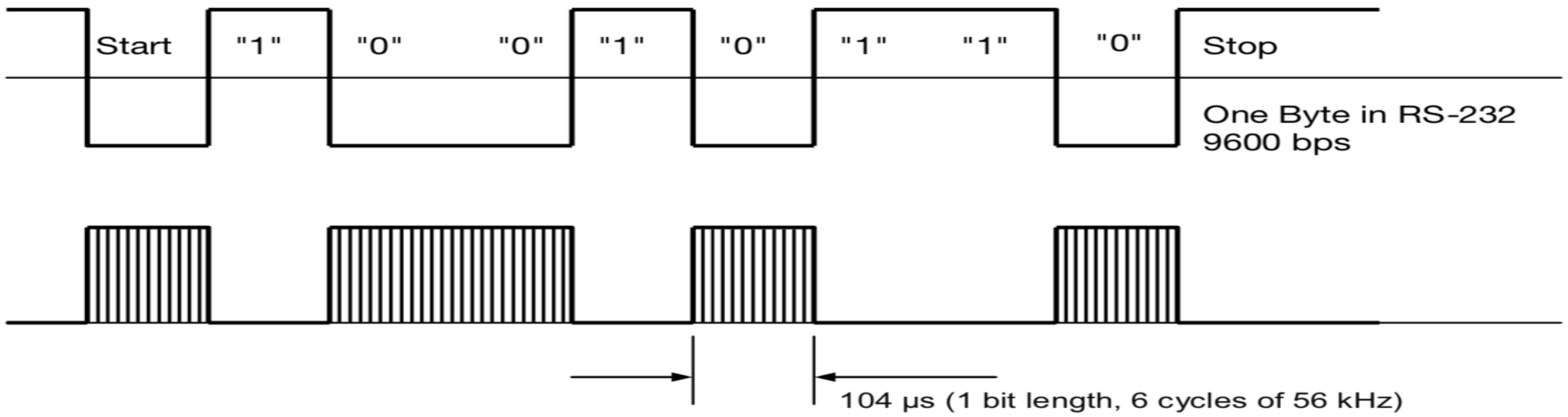


Sensor Characteristics

- A very important characteristic of a sensor is ***accuracy*** *(*which really means inaccuracy)
- **Inaccuracy** is measured as the highest deviation of a value represented by the sensor from the ideal or true value at its input

Sensor Characteristics

- ***Transfer Function:*** An ideal or theoretical input-output relationship exists for every sensor

transfer function

$$y = f(x)$$

output

input

Sensor Characteristics

- ***Transfer Function:*** An ideal or theoretical input-output relationship exists for every sensor

- Examples:

$$y = ax + b$$

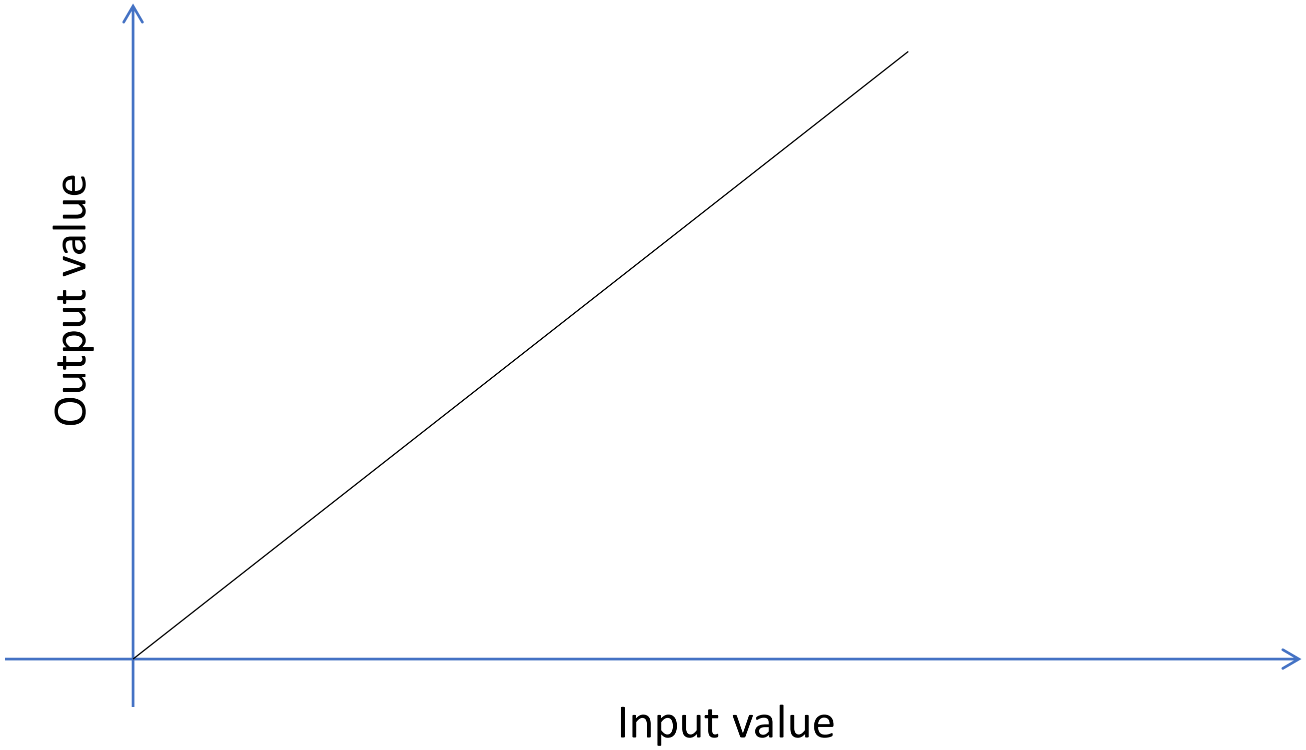
$$y = a + b \ln x$$

$$y = ae^{kx}$$

$$y = a_0 + a_1 x^k$$

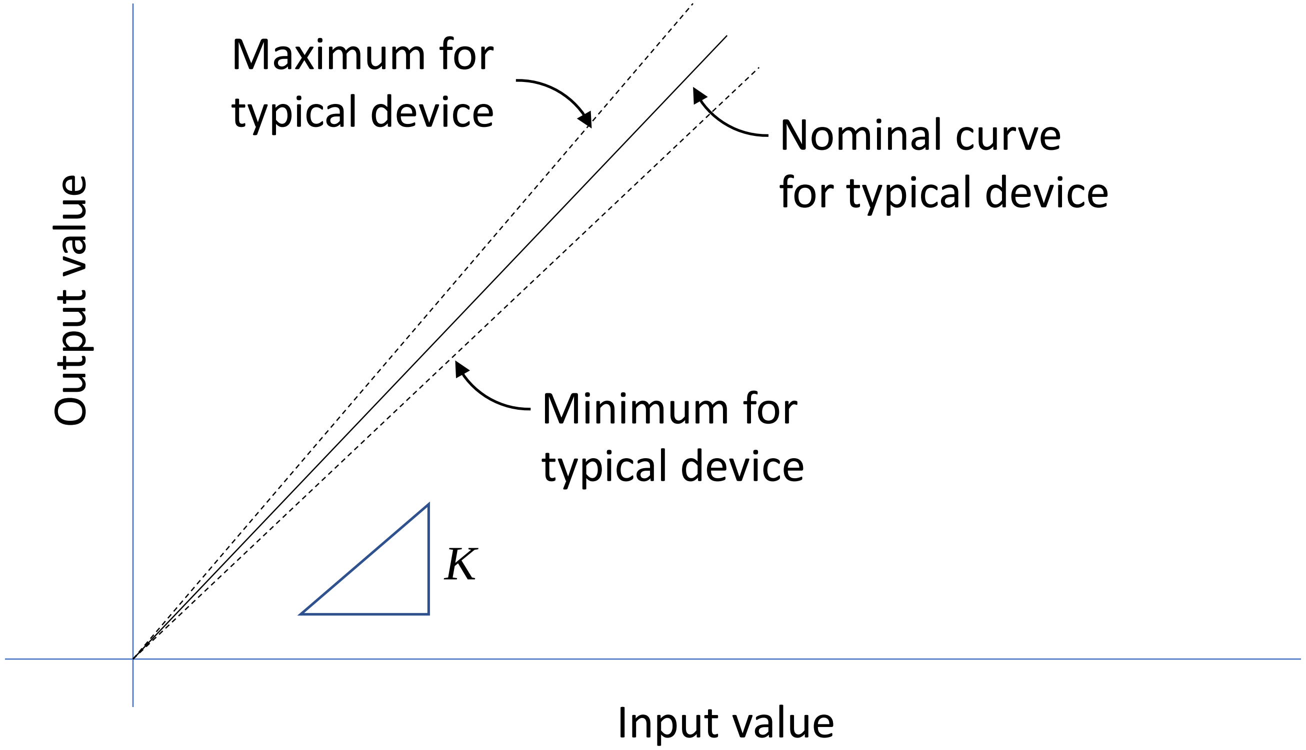
Sensor Characteristics

- In this case we show a nice linear relationship between the input and output values



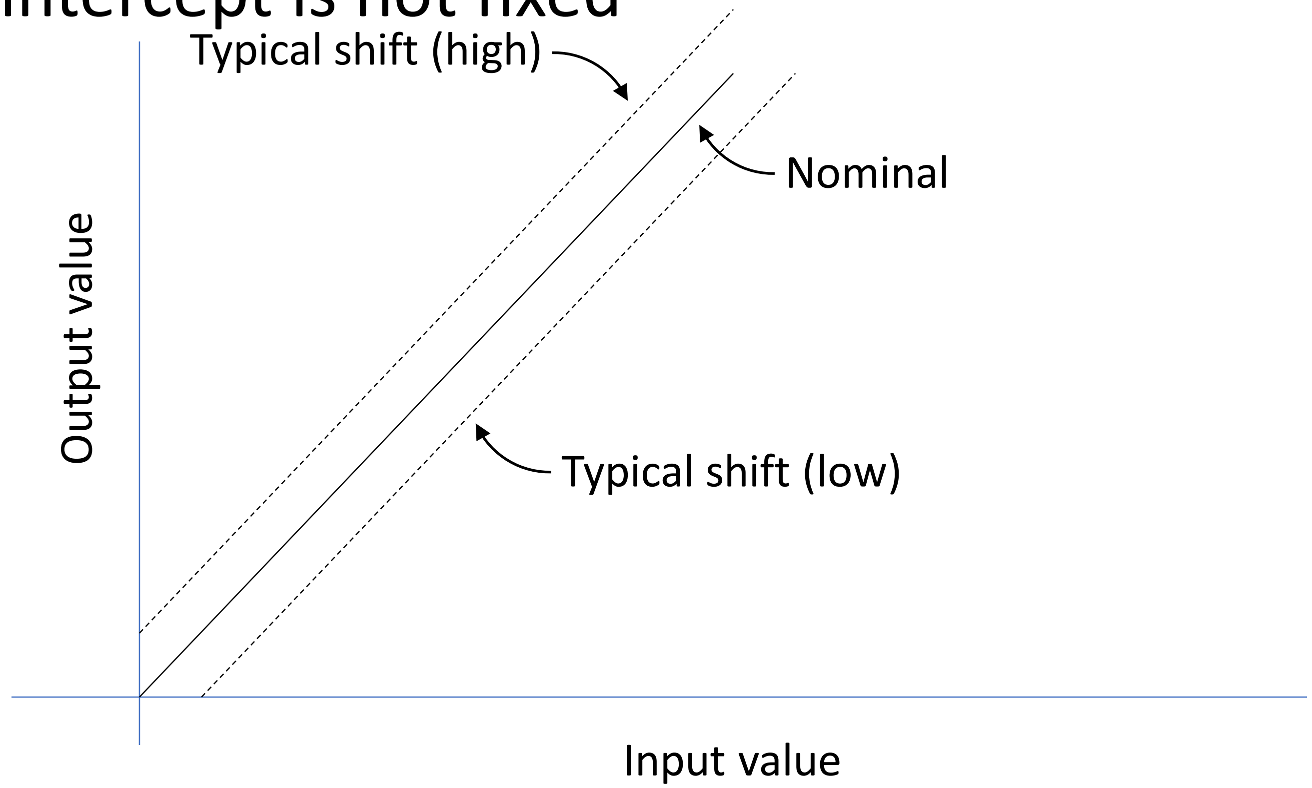
Sensor Characteristics

- ***Sensitivity error*** (e_K) is a statistical measure of the error in the slope of the response curve



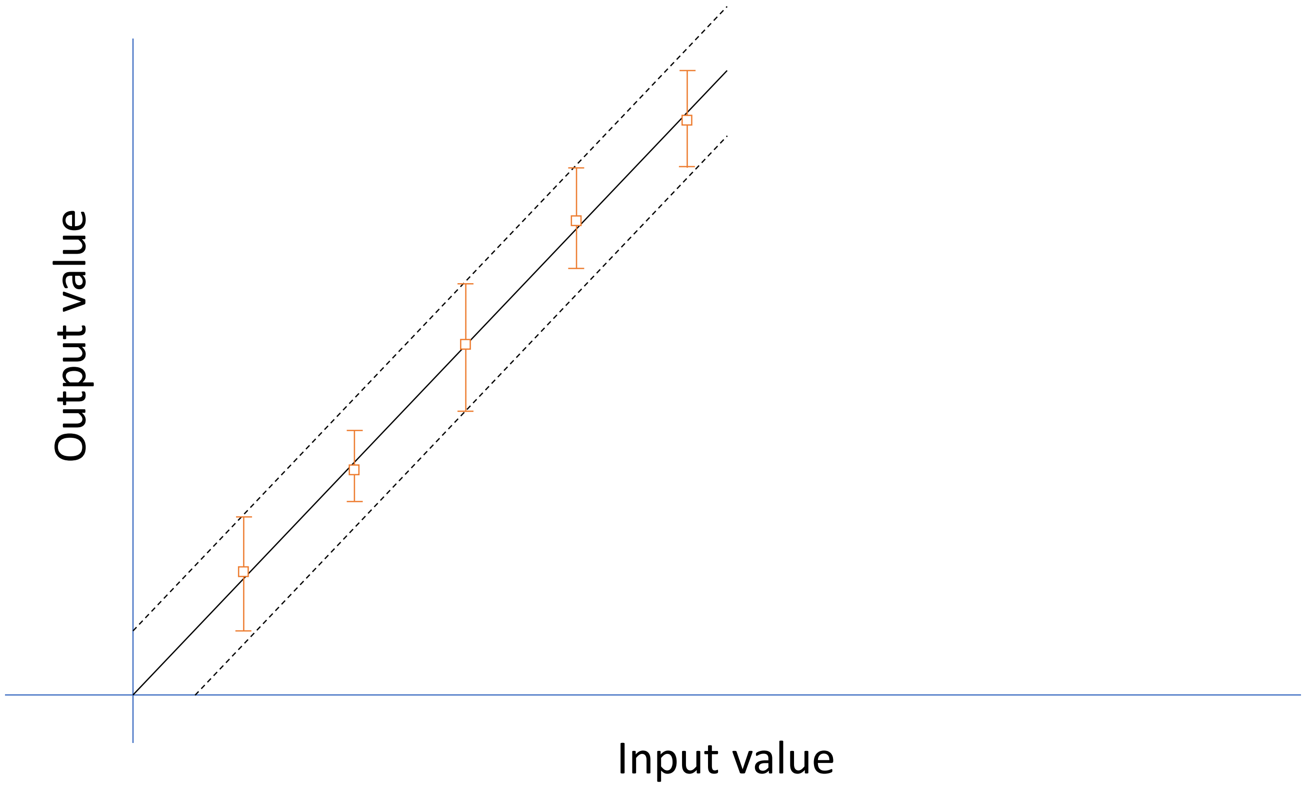
Sensor Characteristics

- ***Zero shift (null) error*** (e_Z) happens when the sensitivity is constant but the zero intercept is not fixed

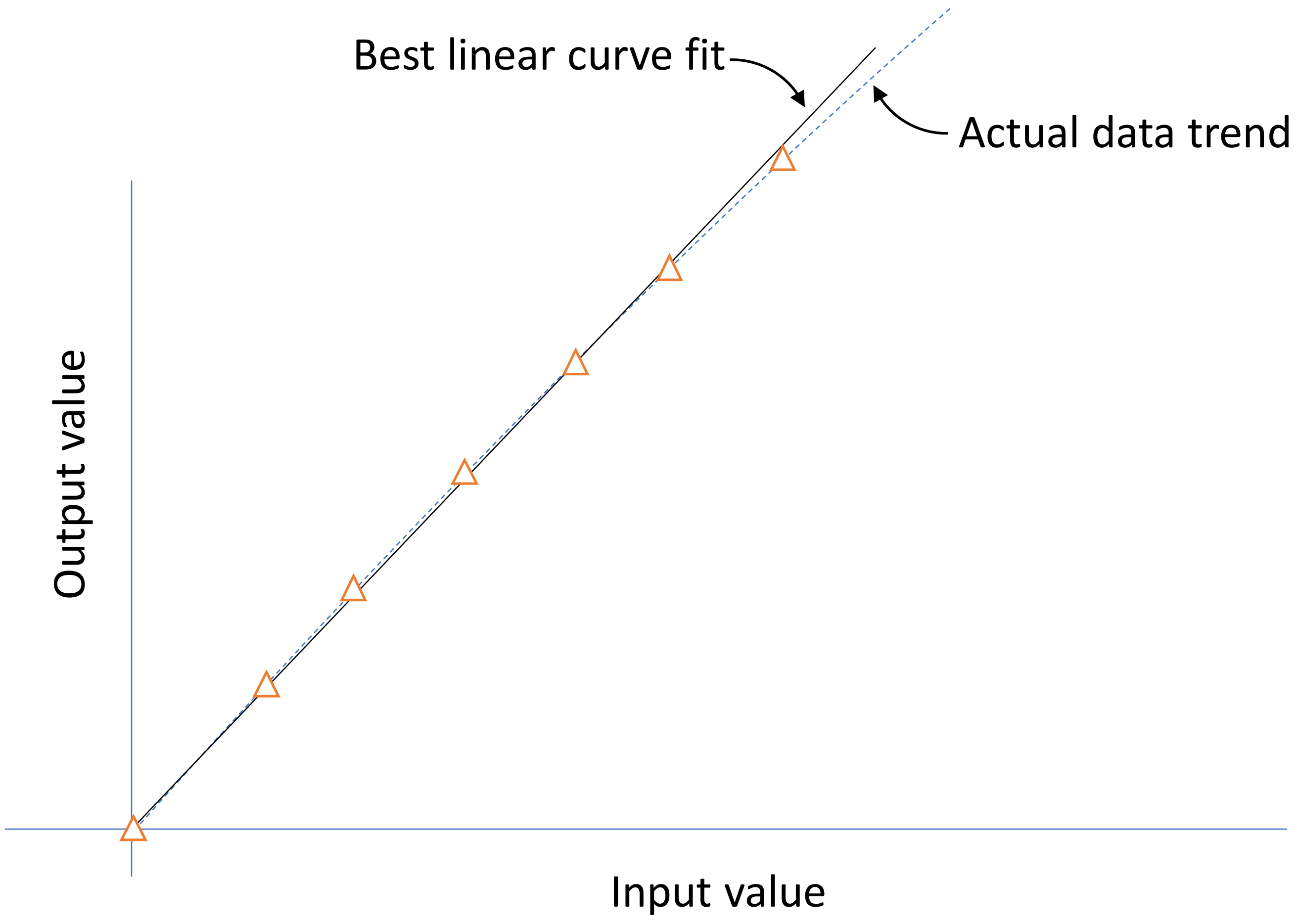


Sensor Characteristics

- ***Repeatability error*** happens when random noise affects subsequent readings



Sensor Characteristics



Sensor Characteristics

- ***Overall instrument error*** or ***uncertainty*** is calculated by combining all of the known errors
- ***Resolution*** is the smallest increment in the measured value that can be discerned
  - Greater uncertainty means lower resolution
  - The representation of the sensor value in the microcontroller also affects resolution

Sensor Characteristics

- ***Calibration*** is the process of determining the form and parameters of the transfer function

Sensing

- Distance sensors
- GPS
- IMU
- Button
- Camera/vision
- Light/IR
- Environmental
- Encoders

A button is about as simple as it gets...but buttons have lots of uses!

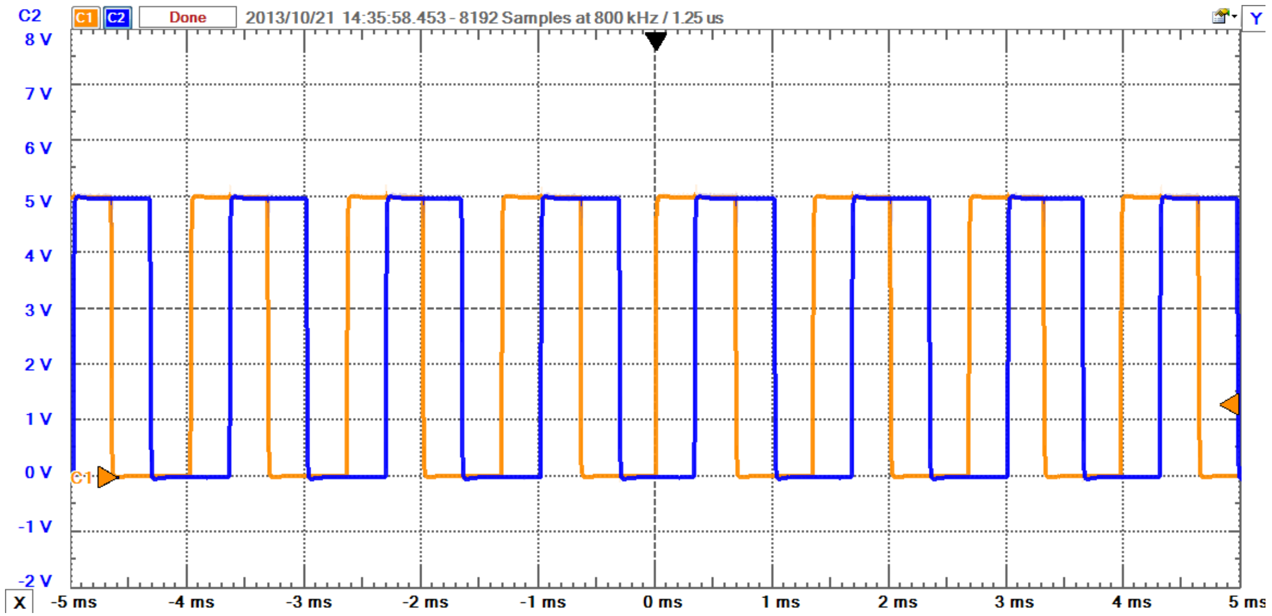
Let’s do some “bottom-up” design!

- What can you use a button for?

OK, let’s do some top-down design!

- How else can I detect an object/obstacle?

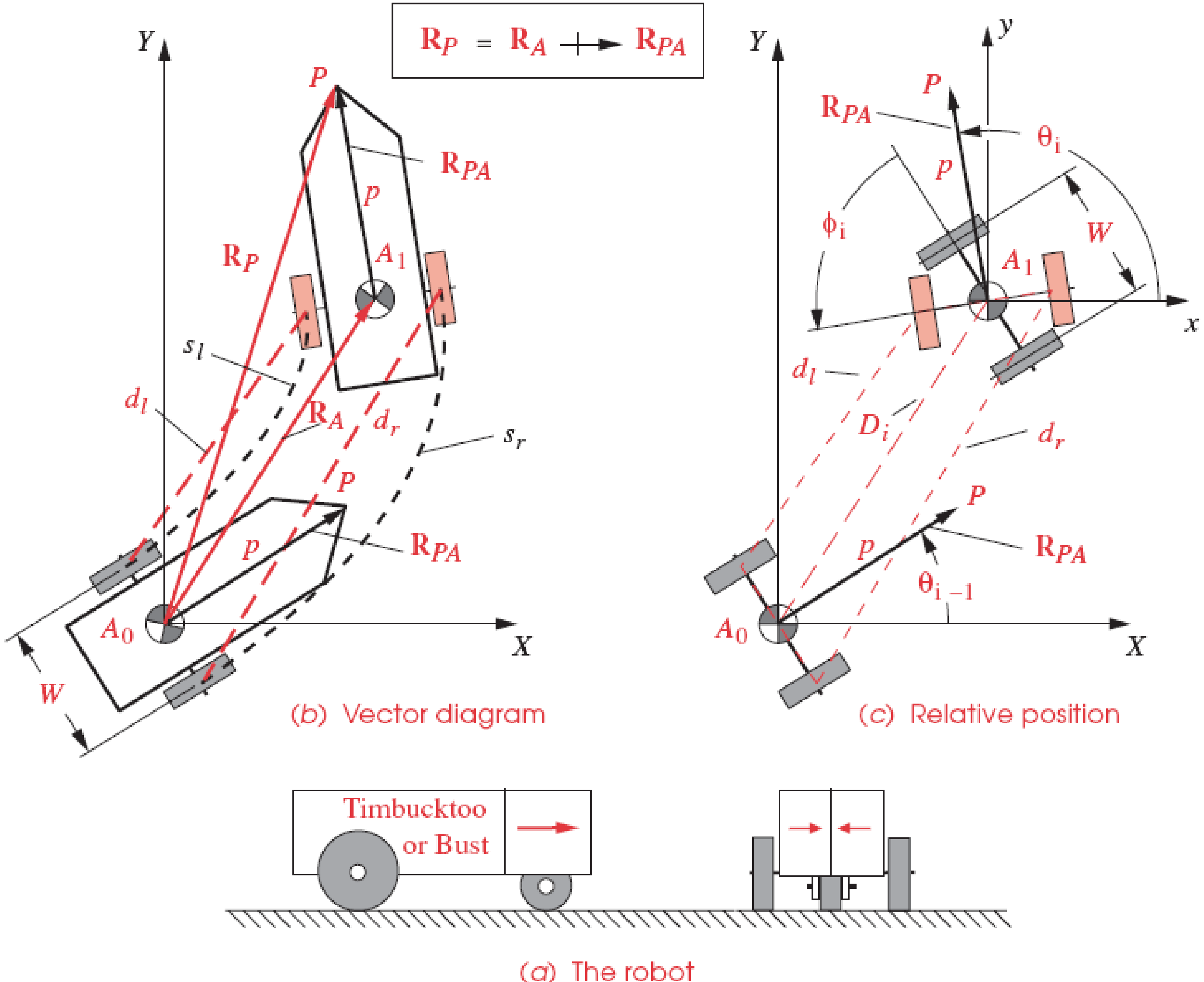
Encoders are useful for motion tracking



Motion tracking

- Odometry
  - Measurement of relative motion from some starting point using *internal* sensors
    - A car has a trip odometer that measures how far it’s been driven since the last reset
- Dead reckoning
  - A mathematical procedure for updating the estimated location over a short period of time

Dead Reckoning



Odometry

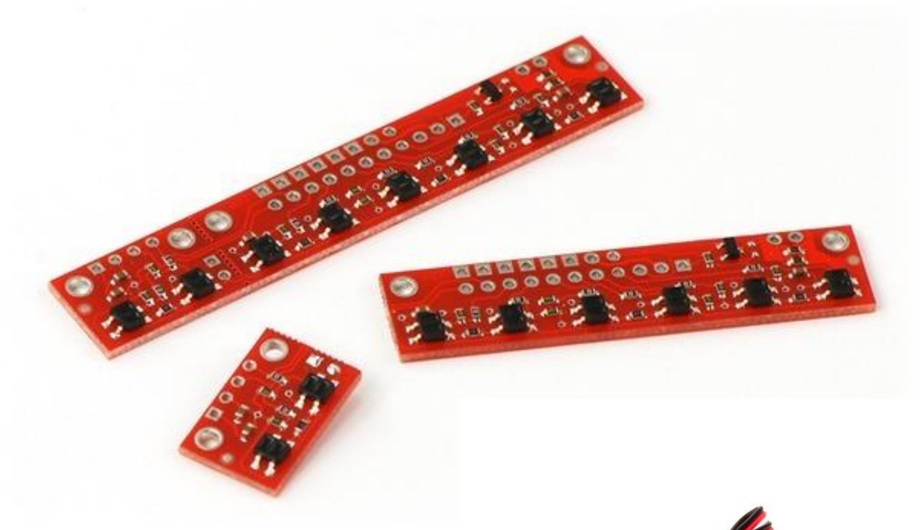
- Good short-term accuracy
- Inexpensive
- High sampling rates

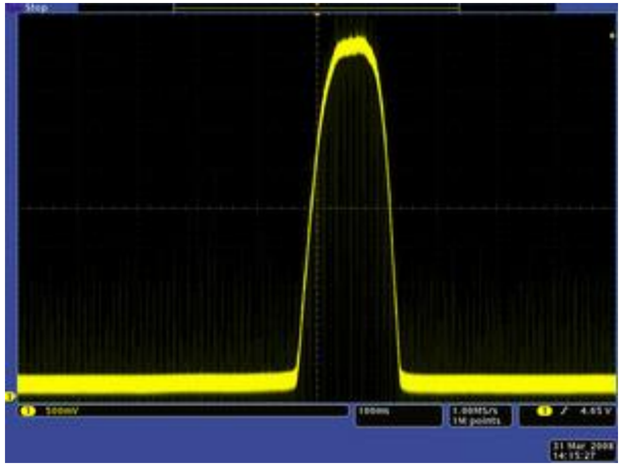
- Unbounded accumulation of errors
  - Systematic
    - Kinematic imperfections of the robot
  - Non-systematic
    - Caused by the interaction of the ground surface with the wheels

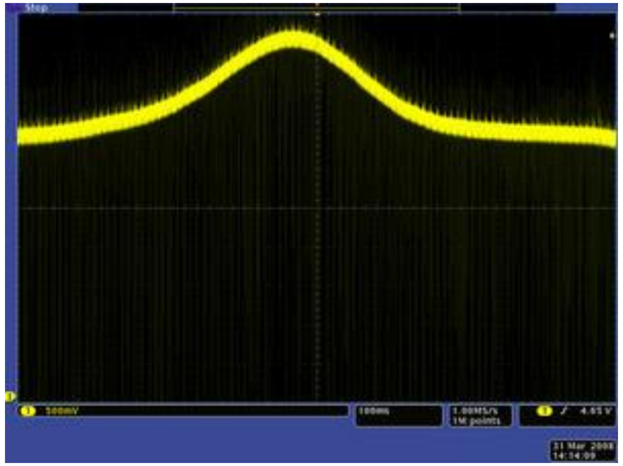
Localization

- OK, so what are some other ways I can keep track of my location or movement?

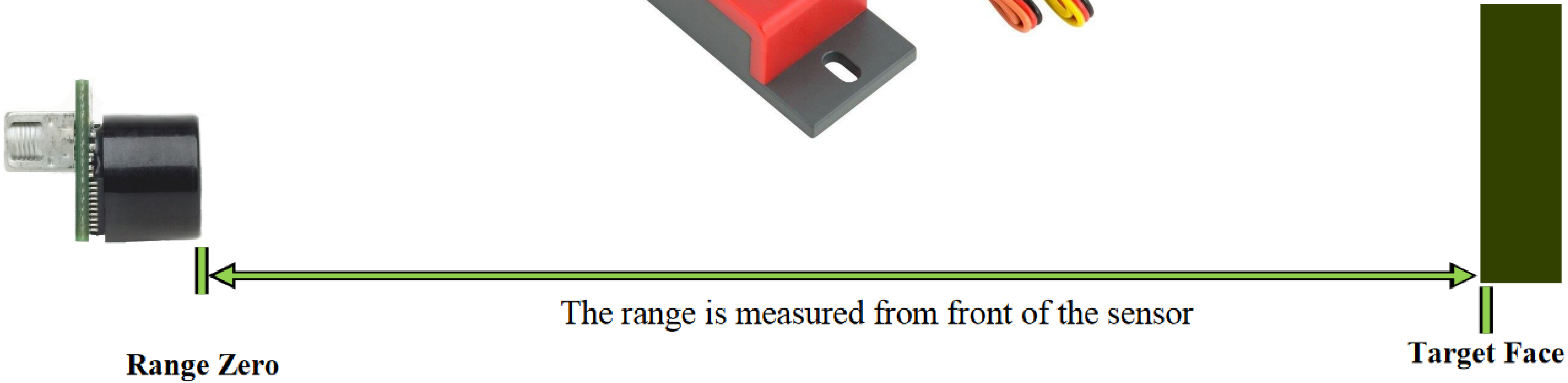
Line tracking is another means of tracking motion



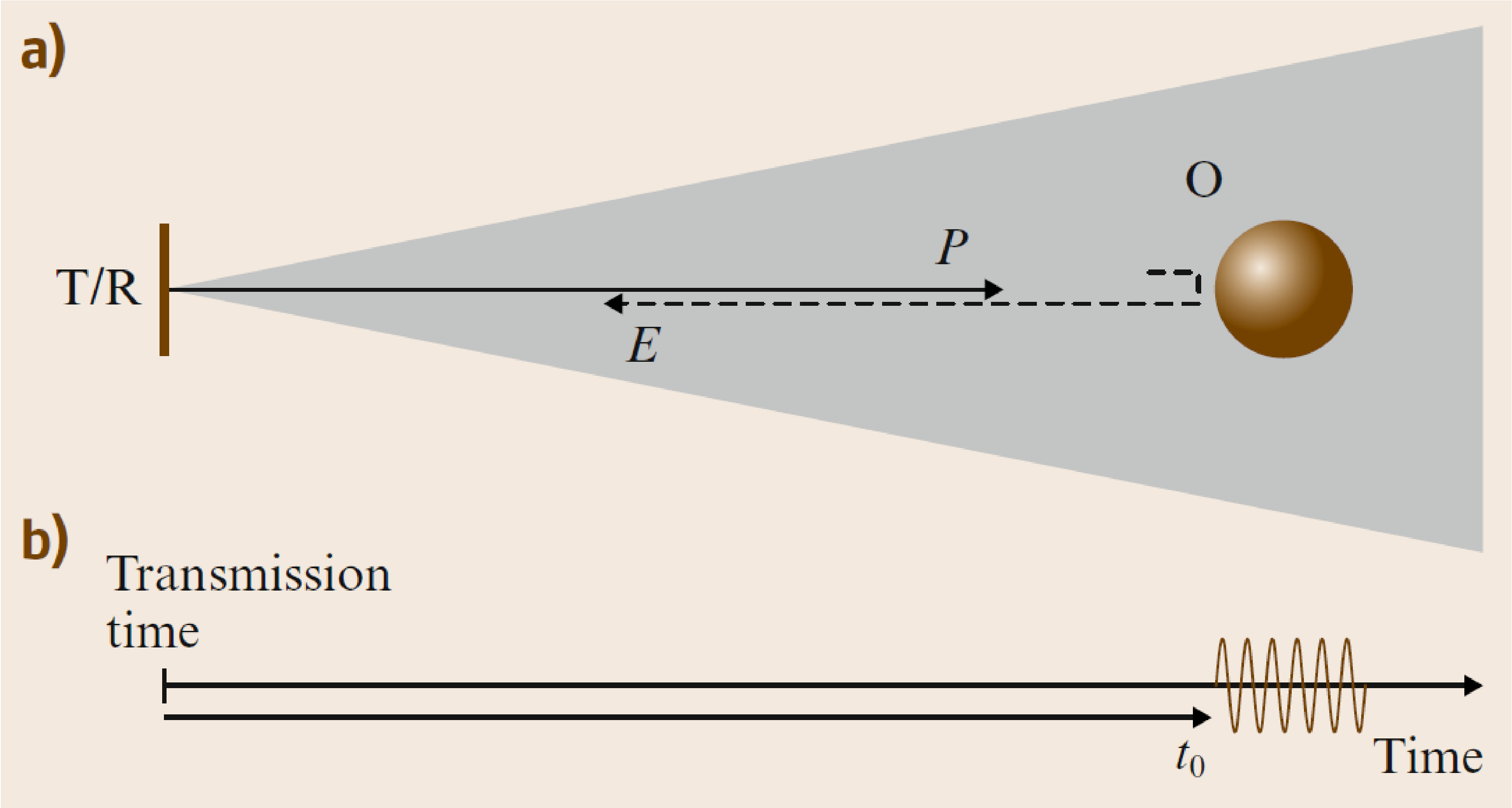




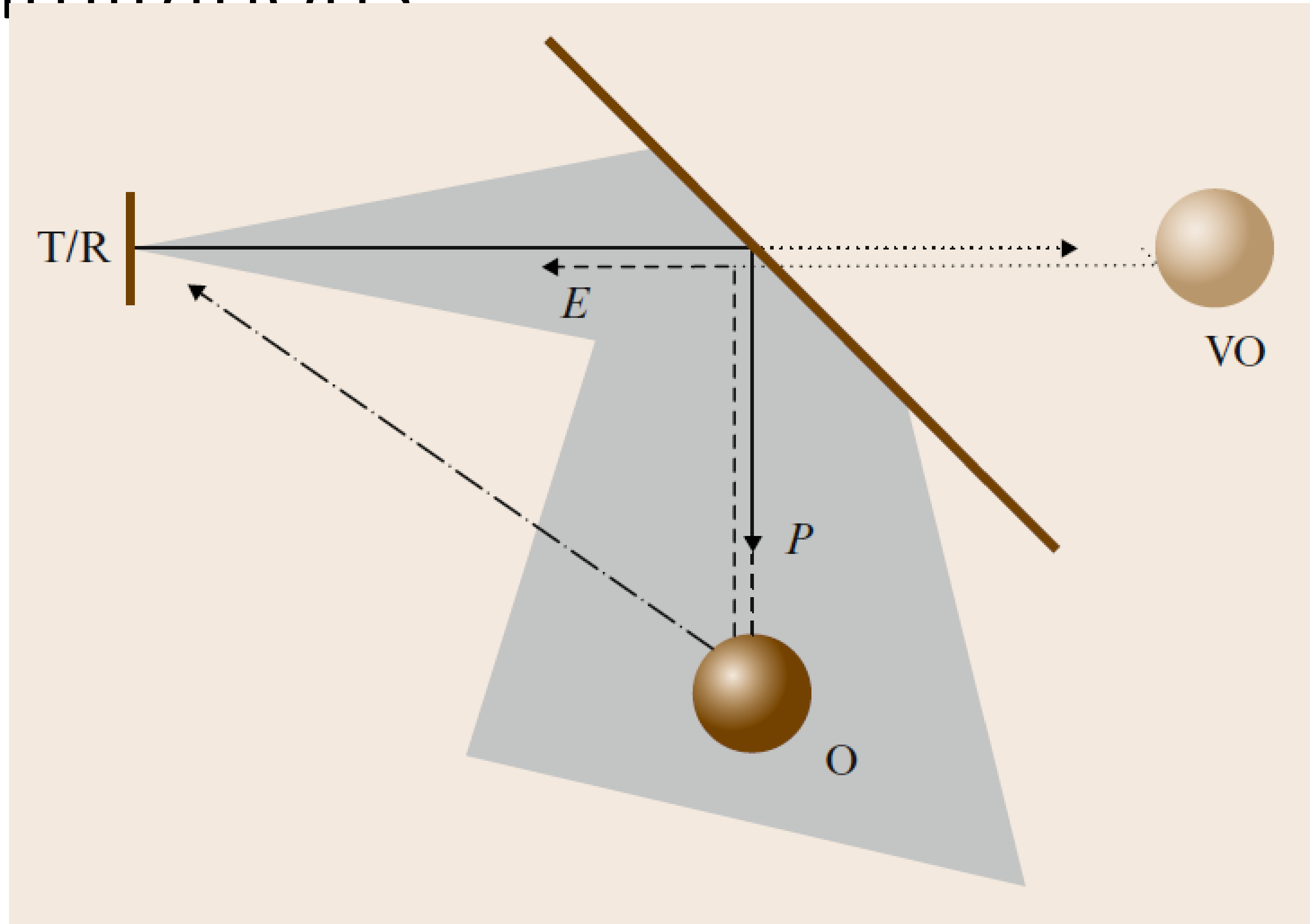
The ultrasonic sensor uses the ‘legacy’ analog interface



Sonar Ranging Principles



Sonar Limitations



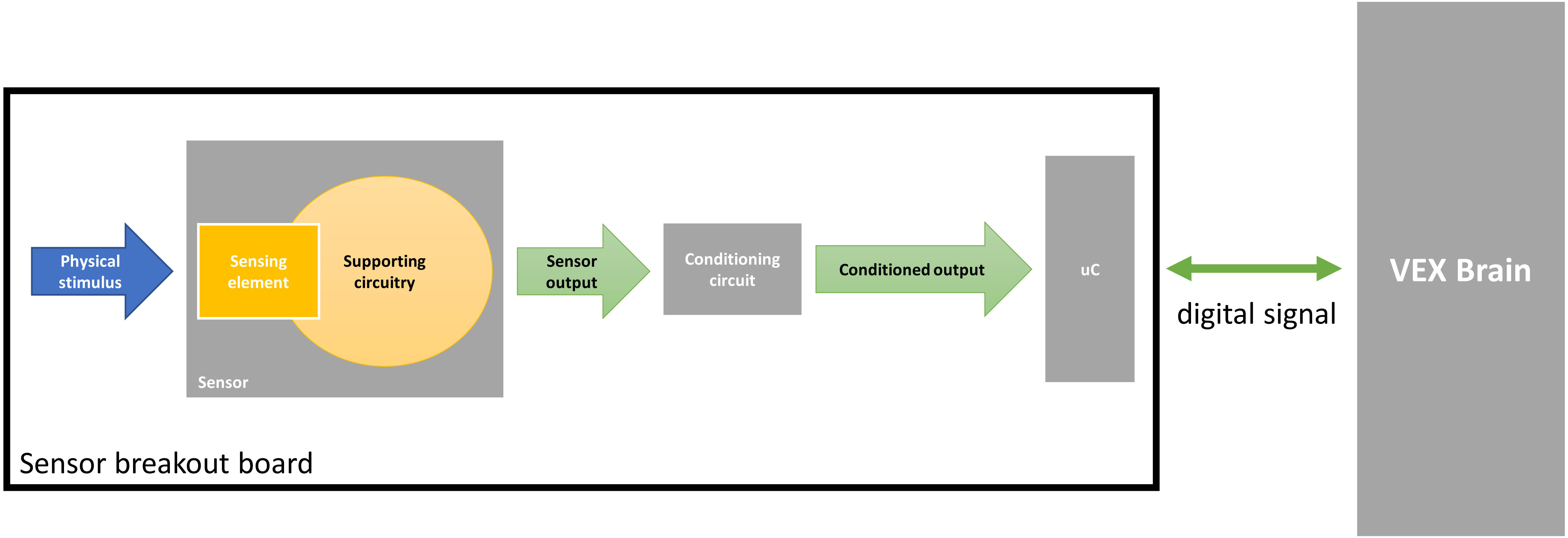
Limitations of Sonar

- The wide sonar beam causes poor directional resolution
- The slow sound speed, relative to an optical sensor, reduces the sonar sensing rate
- Smooth surfaces at oblique incidence do not produce detectable echoes
- Artifacts caused by beam side-lobes and multiple reflections produce range readings in the environment where no objects exist

VEX uses both digital and analog interfaces

Amplification

- Amplification is used to increase the intensity of a signal



Passive light sensors