Sensors

By Nilesh Patidar

What are sensors?

- There are a vast number of different sensors being used in robotics,applying different measurement techniques, and using different interfaces to a controller.
- The scope of this chapter is more on interfacing sensors to controllers than on understanding the internal construction of sensors themselves.
- Most important thing is to find the right sensor for a particular application. This includes-
  - right measurement technique
  - right size and weight
  - right operating temperature range and power consumption,
  - and of course the right price range.
- Data transfer from the sensor to the CPU can be either CPU-initiated (polling) or sensor-initiated (via interrupt).

Examples

Sensor Categories

From a robot's point of view, it is more important to distinguish:
- Local or on-board sensors(sensors mounted on the robot)
- Global sensors (sensors mounted outside the robot in its environment and transmitting sensor data back to the robot)

For mobile robot systems it is also important to distinguish:
- Internal or proprioceptive sensors (sensors monitoring the robot's internal state)
- External sensors(sensors monitoring the robot's environment

A further distinction is between:
- Passive sensors(sensors that monitor the environment without disturbing it,for example digital camera, gyroscope)
- Active sensors(sensors that stimulate the environment for their measurement,for example sonar sensor, laser scanner, infrared sensor)

Sensors Classification

Analog v/s Digital Sensors

A number of sensors produce analog output signals rather than digital signals. This means an A/D converter (analog to digital converter) is required to connect such a sensor to a microcontroller.

Typical examples of such sensors are:
- Microphone
- Analog infrared distance sensor
- Analog compass
- Barometer sensor

Digital sensors on the other hand are usually more complex than analog sensors and often also more accurate. In some cases the same sensor is available in either analog or digital form, where the latter one is the identical analog sensor packaged with an A/D converter.

The output signal of digital sensors can have different forms. It can be a parallel interface (for example 8 or 16 digital output lines), a serial interface (for example following the RS232 standard) or a "synchronous serial" interface.

Different Types of Sensors

Binary Sensor

Shaft Encoder

Position Sensitive Device

Compass

Orientation Sensors

- Orientation sensors to determine a robot's orientation in 3D space are required for projects like tracked robots, balancing robots ,walking robots , or autonomous planes.
- A variety of sensors are available for this purpose, up to complex modules that can determine an object's orientation in all three axes.
- We will concentrate here on simpler sensors, most of them only capable of measuring a single dimension. Two or three sensors of the same model can be combined for measuring two or all three axes of orientation.

A/D Converter

- An A/D converter translates an analog signal into a digital value. The characteristics of an A/D converter include:
  - Accuracy expressed in the number of digits it produces per value (for example 10 bit A/D converter)
  - Speed expressed in maximum conversions per second(for example 500 conversions per second)
  - Measurement range expressed in volts (for example 0..5V)
- A/D converters come in many variations. The output format also varies.
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Digital Camera

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Examples

Sensor Output	Sample Application
Binary signal (0 or 1)	Tactile sensor
Analog signal (e.g. 0..5V)	Inclinometer
Timing signal (e.g. PWM)	Gyroscope
Serial link (RS232 or USB)	GPS module
Parallel link	Digital camera

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Sensors Classification

	Local	Global
Internal	**Passive** battery sensor, chip-temperature sensor, shaft encoders, accelerometer, gyroscope, inclinometer, compass **Active** –	**Passive** – **Active** –
External	**Passive** on-board camera **Active** sonar sensor, infrared distance sensor, laser scanner	**Passive** overhead camera, satellite GPS **Active** sonar (or other) global positioning system

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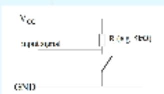

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There are several techniques for building an encoder.
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- Digital compasses are considerably more complex, but also provide a much higher directional resolution. The sensor we selected for most of our projects has a resolution of 1° and accuracy of 2°, and it can be used indoors.
  - Vector 2X

Orientation Sensors

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Accelerometer

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Digital Camera

Digital Camera

Camera Sensor Hardware

Camera Interface

Camera Sensor Data

Camera Driver

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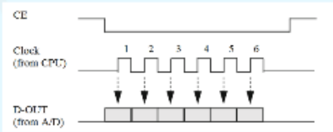

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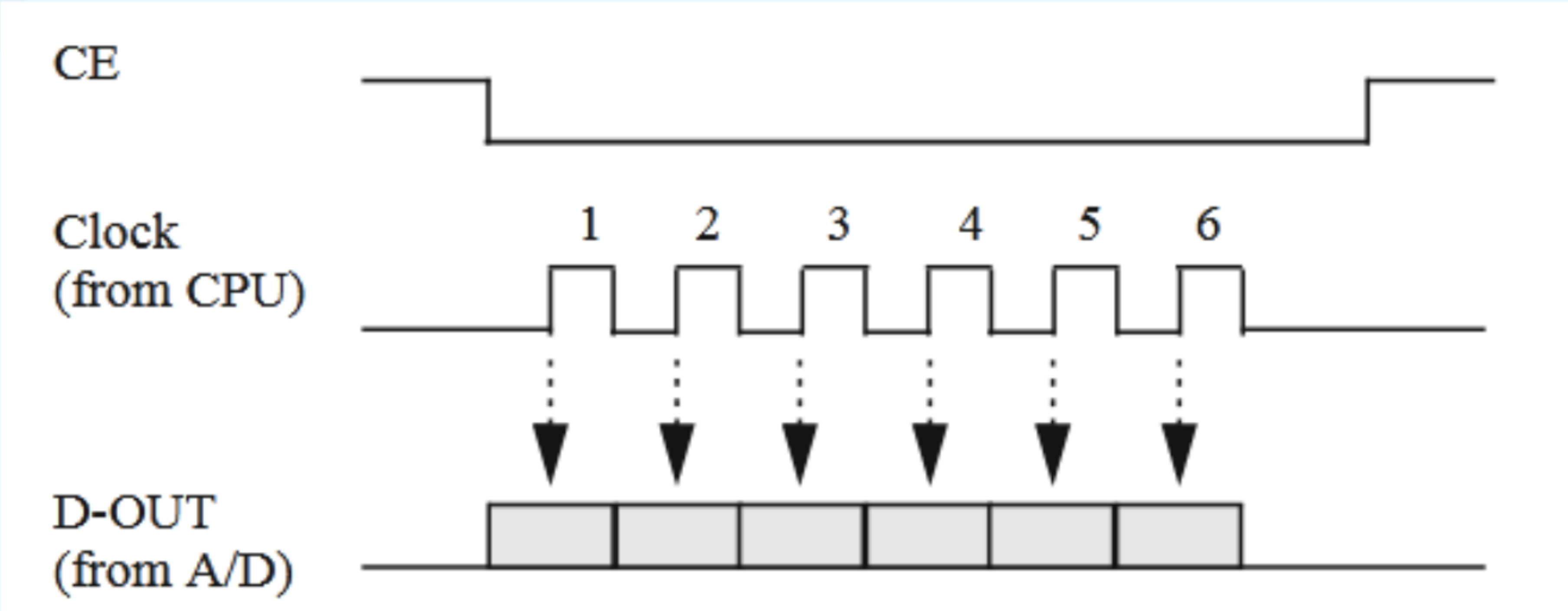

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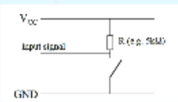

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There are several techniques for building an encoder.
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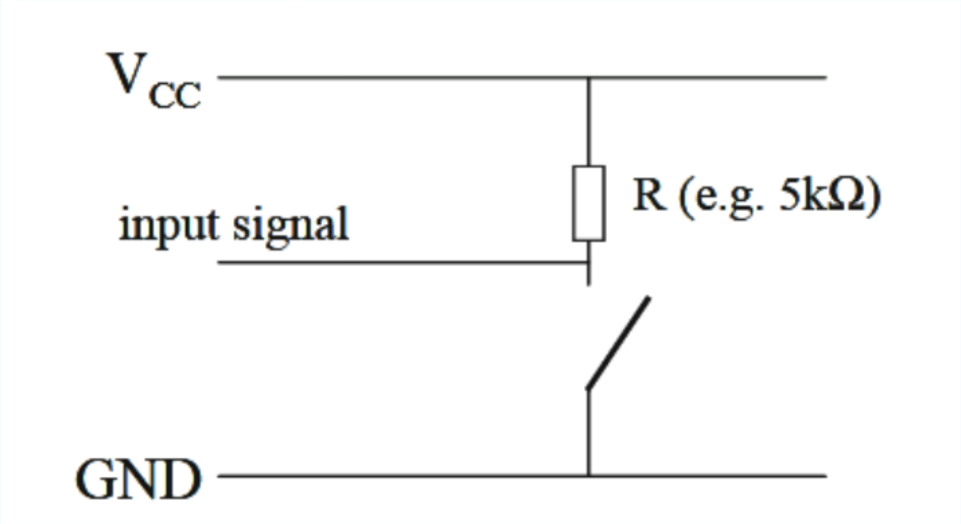

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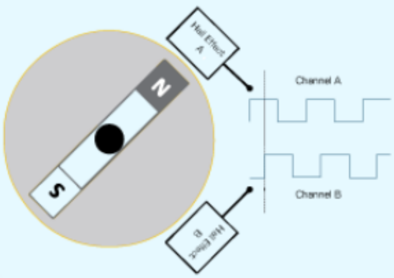
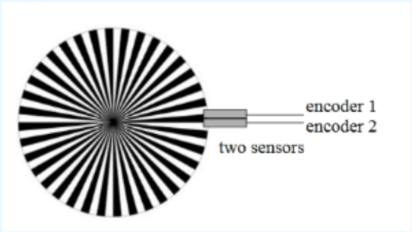
Magnetic Encoders

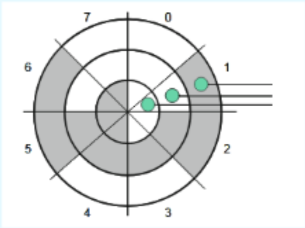
Magnetic encoders use a Hall-effect sensor and a rotating disk on the motor shaft with a number of magnets (for example 16) mounted in a circle. Every revolution of the motor shaft drives the magnets past the Hall sensor and there fore results in 16 pulses or "ticks" on the encoder line.



Optical Encoders

Standard optical encoders use a sector disk with black and white segments together with an LED and a photo-diode. The photo-diode detects reflected light during a white segment, but not during a black segment. So once again, if this disk has16 white and 16 black segments, the sensor will receive 16 pulses during one revolution.





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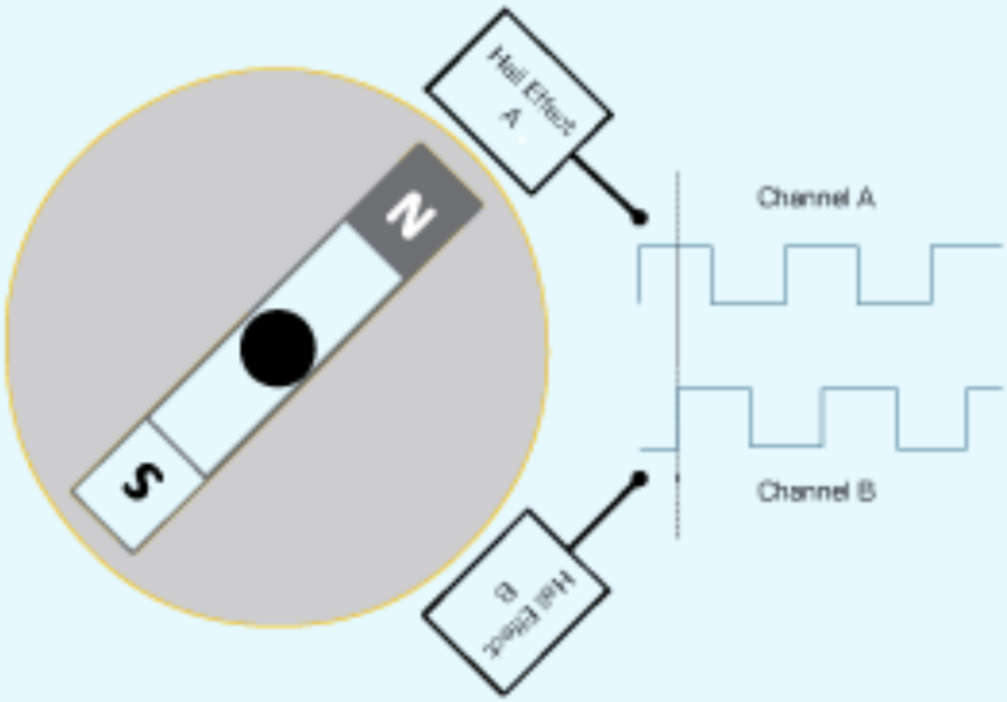

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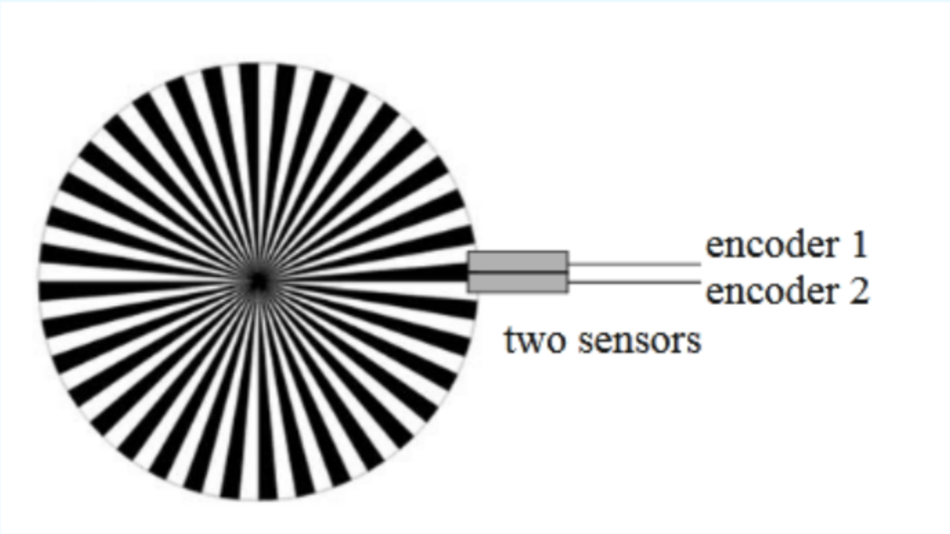

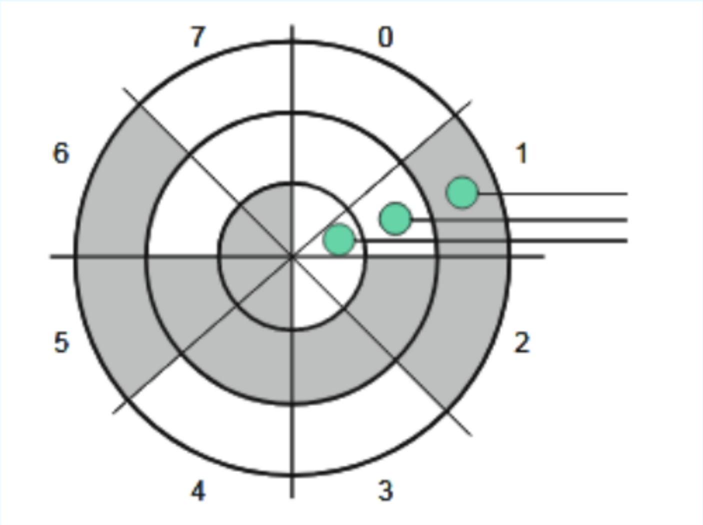

Position Sensitive Device

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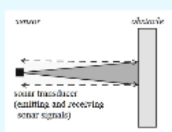
Sonar Sensors

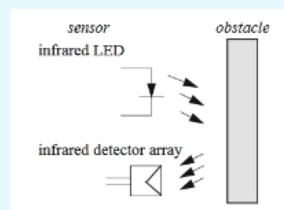
- Most robots have been equipped with sonar sensors because of the relatively narrow cone of these sensors, a typical configuration to cover the whole circumference of a round robot required 24sensors, mapping about 15° each.
- Sonar sensors use the following principle: a short acoustic signal of about 1ms at an ultrasonic frequency of 50kHz to 250kHz is emitted and the time is measured from signal emission until the echo returns to the sensor.
- The measured time-of-flight is proportional to twice the distance of the nearest obstacle in the sensor cone.
- If no signal is received within a certain time limit, then no obstacle is detected within the corresponding distance. Measurements are repeated about 20 times per second, which gives this sensor its typical clicking sound

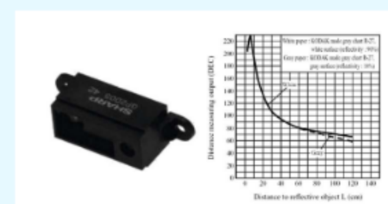


Infrared Sensors

Today, in many mobile robot systems, sonar sensors have been replaced by either infrared sensors or laser sensors.
these systems typically use a pulsed infrared LED at about 40kHz together with a detection array. The angle under which the reflected beam is received changes according to the distance to the object and therefore can be used as a measure of the distance. There are two variations of this sensor:

- Sharp GP2D12 with analog output
- Sharp GP2D02 with digital serial output





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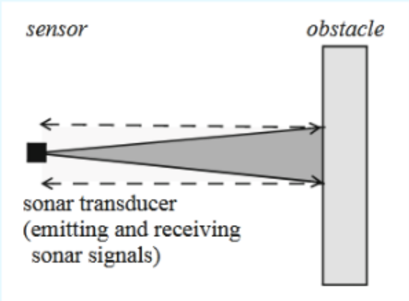

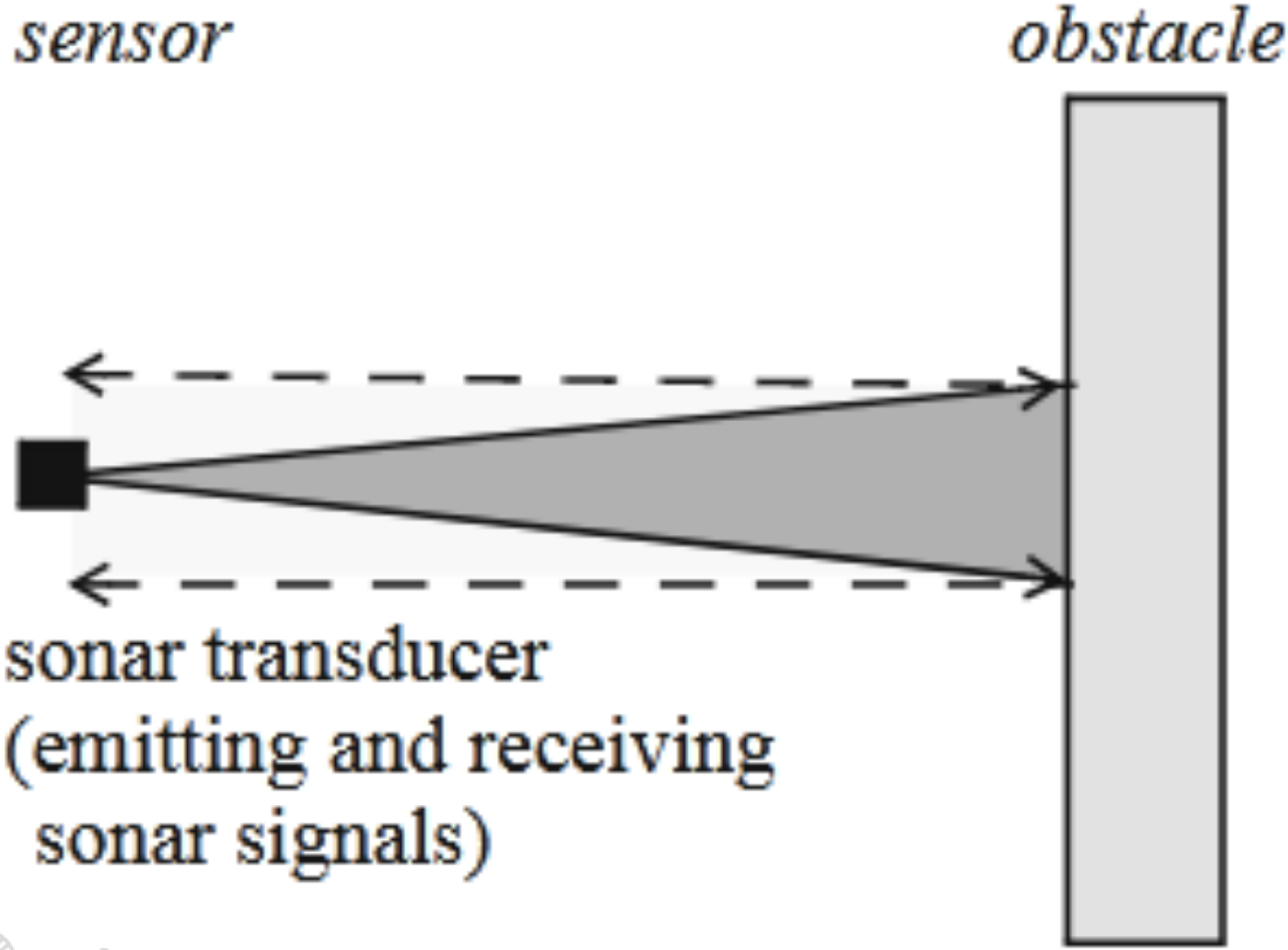
sensor
obstacle
sonar transducer
(emitting and receiving
sonar signals)

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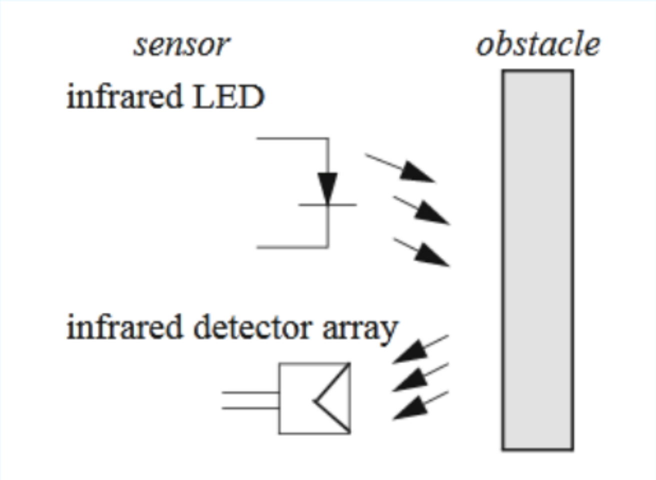
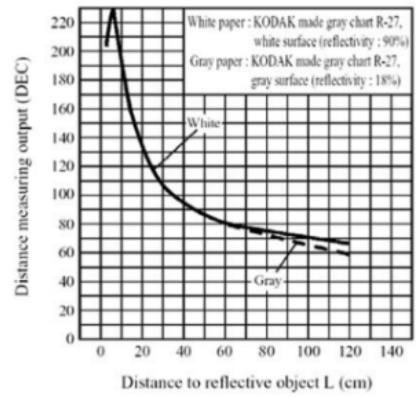
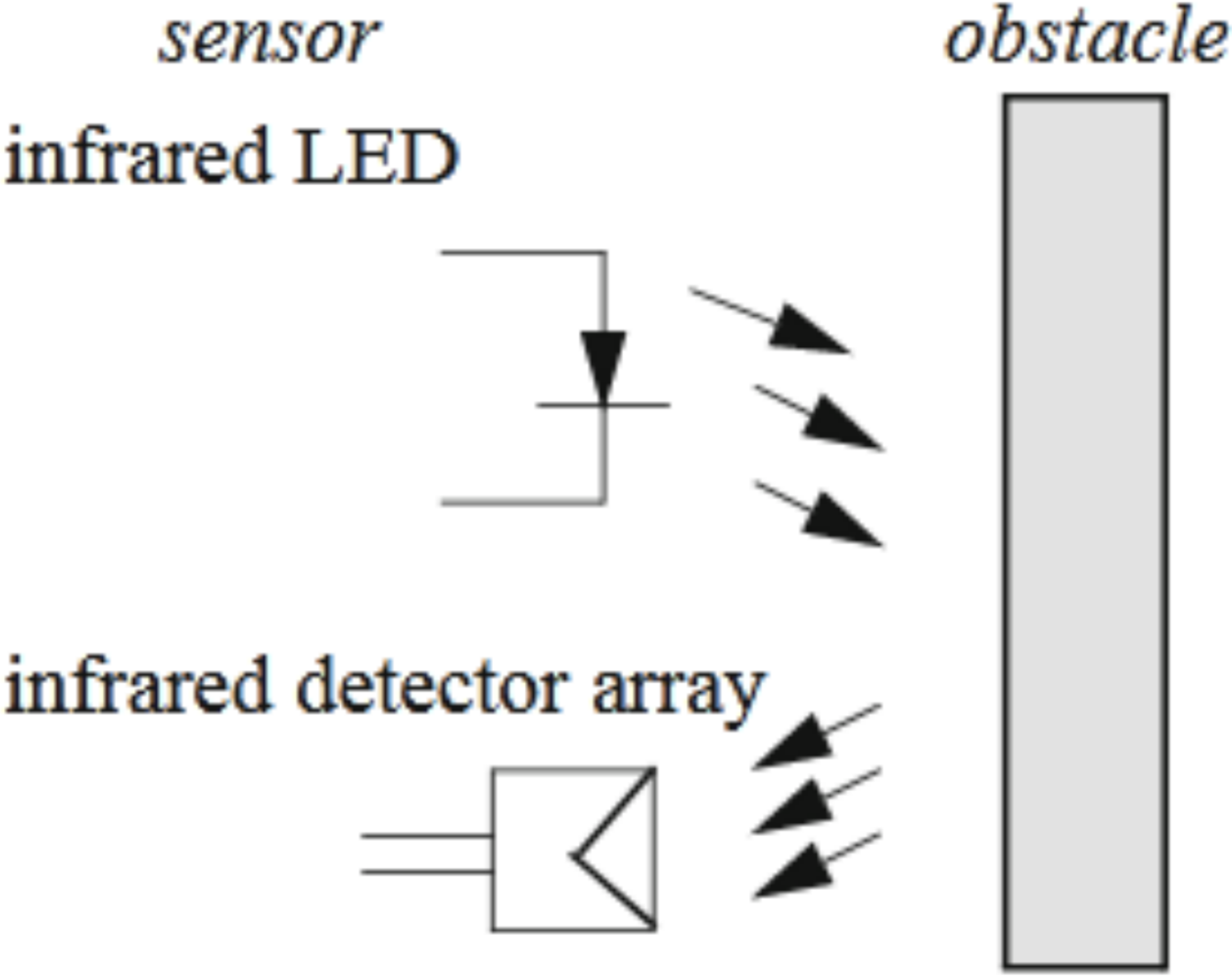
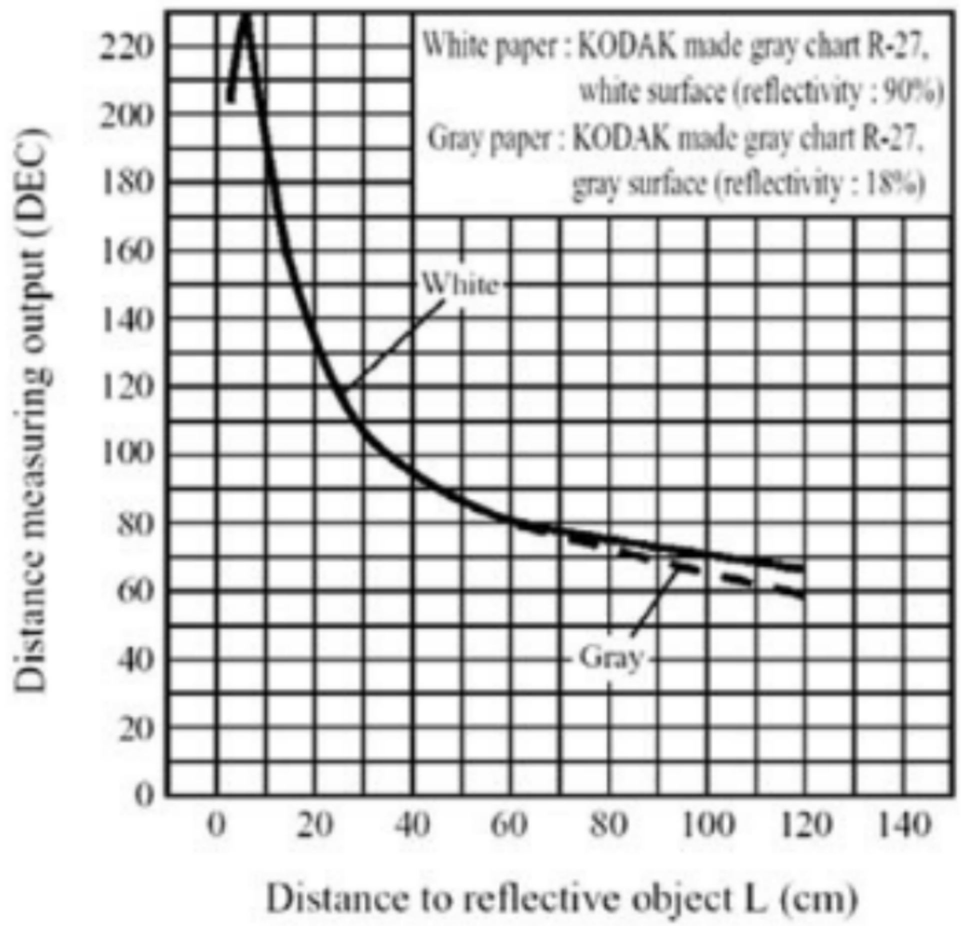





sensor
obstacle
infrared LED
infrared detector array

output


SHARP
GP2D05 42


White paper : KODAK made gray chart R-27, white surface (reflectivity : 90%)
Gray paper : KODAK made gray chart R-27, gray surface (reflectivity : 18%)
White
Gray
Distance measuring output (DEC)
0
20
40
60
80
100
120
140
160
180
200
220
0
20
40
60
80
100
120
140
Distance to reflective object L (cm)

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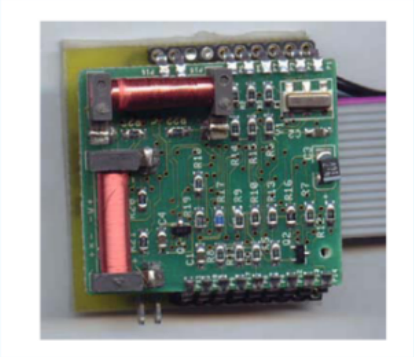

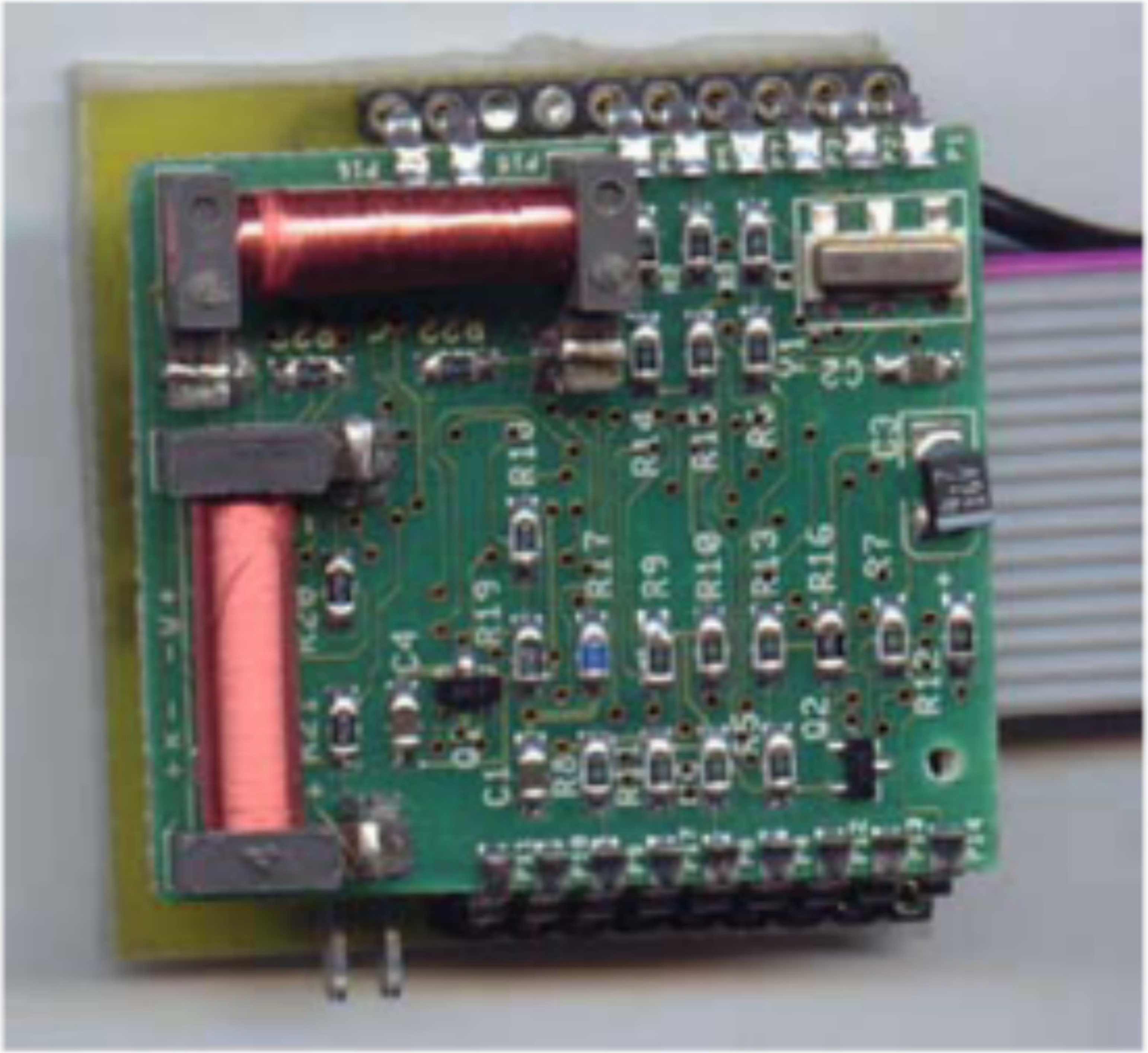
R19
R17
R9
R10
R13
R16
C4
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Q2
R12

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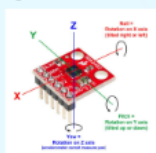
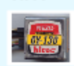
Accelerometer

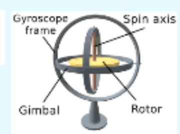
- A number of different accelerometer models are available from Analog Devices, measuring a single or two axes at once.
- Sensor output is either analog or a PWM signal that needs to be measured and translated back into a binary value by the CPU's timing processing unit.
- Accelerometer Measuring the acceleration along one axis
  - Analog Devices ADXL05 (single axis, analog output)
  - Analog Devices ADXL202 (dual axis, PWM output)



Gyroscope

- These modules are meant to be connected between the receiver and a servo actuator, so they have a PWM input and a PWM output.
- In normal operation, for example in a model helicopter, the PWM input signal from the receiver is modified according to the measured rotation about the gyroscope's axis, and a PWM signal is produced at the sensor's output, in order to compensate for the angular rotation.
- Gyroscope Measuring the rotational change of orientation about one axis-
  - HiTec GY 130 Piezo Gyro (PWM input and output)



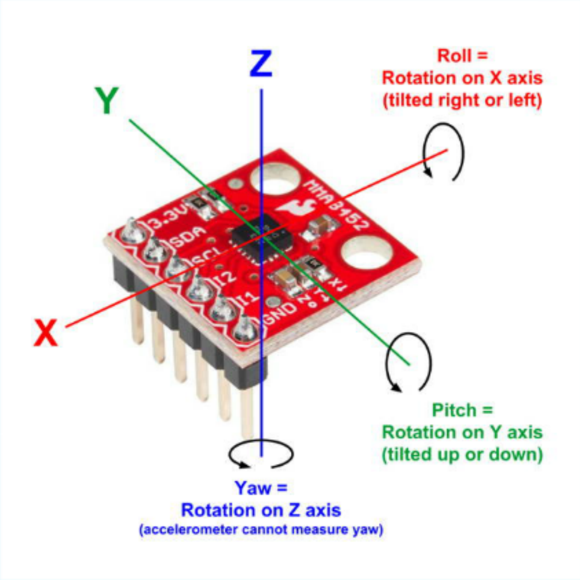


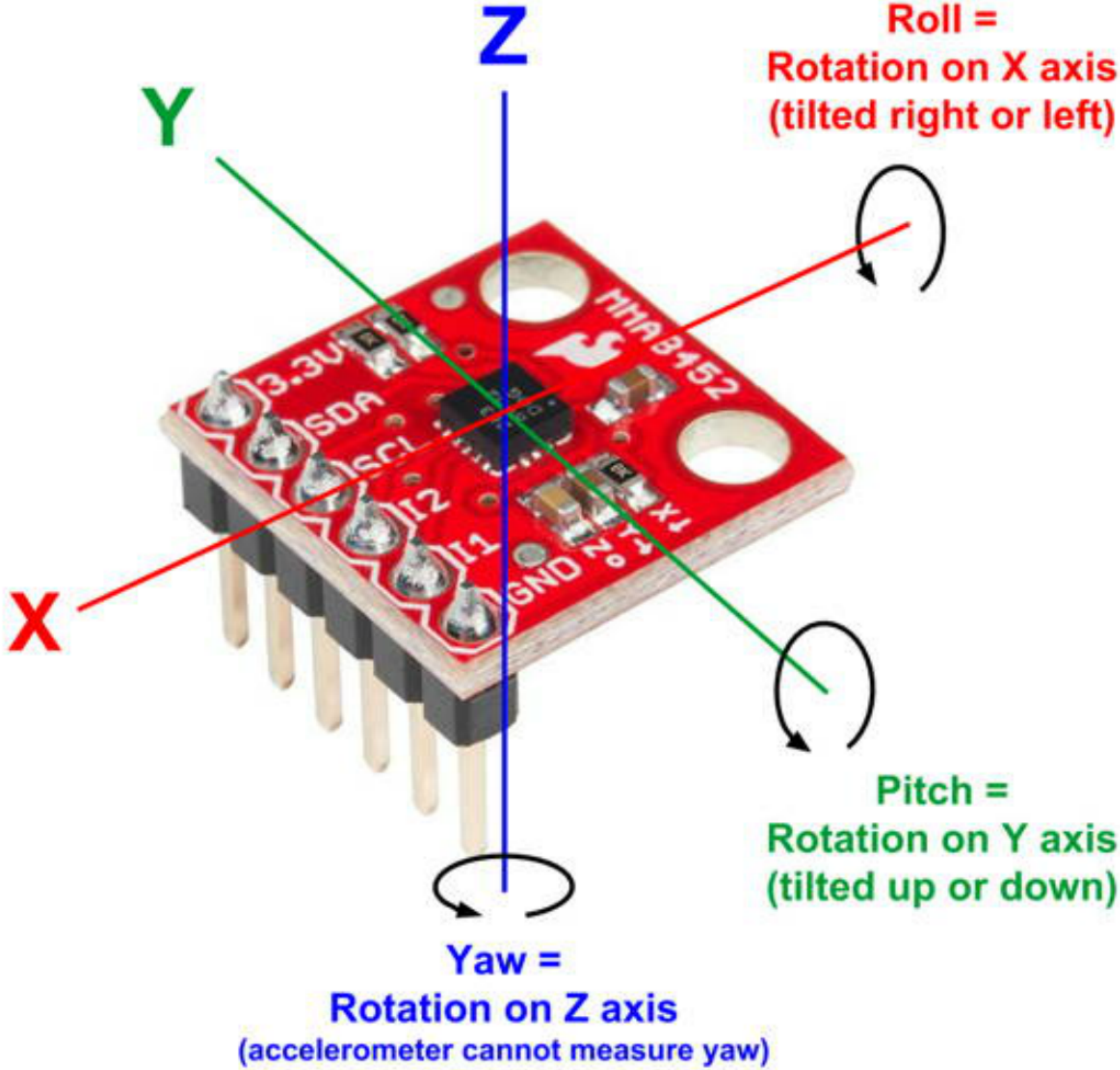
Inclinometer

- Inclinometers measure the absolute orientation angle within a specified range,depending on the sensor model.
- The sensor output is also model-dependent,with either analog signal output or PWM being available. Therefore, interfacing to an embedded system is identical to accelerometers.
- Inclinometer Measuring the absolute orientation angle about one axis
  - Seika N3(analog output)
  - Seika N3d(PWM output)

Accelerometer

- A number of different accelerometer models are available from Analog Devices, measuring a single or two axes at once.
- Sensor output is either analog or a PWM signal that needs to be measured and translated back into a binary value by the CPU's timing processing unit.
- Accelerometer Measuring the acceleration along one axis
  - Analog Devices ADXL05 (single axis, analog output)
  - Analog Devices ADXL202 (dual axis, PWM output)




Z
Y
X
Roll =
Rotation on X axis
(tilted right or left)
Pitch =
Rotation on Y axis
(tilted up or down)
Yaw =
Rotation on Z axis
(accelerometer cannot measure yaw)
3.3V
SDA
SCL
I2
I1
GND
MMA8452

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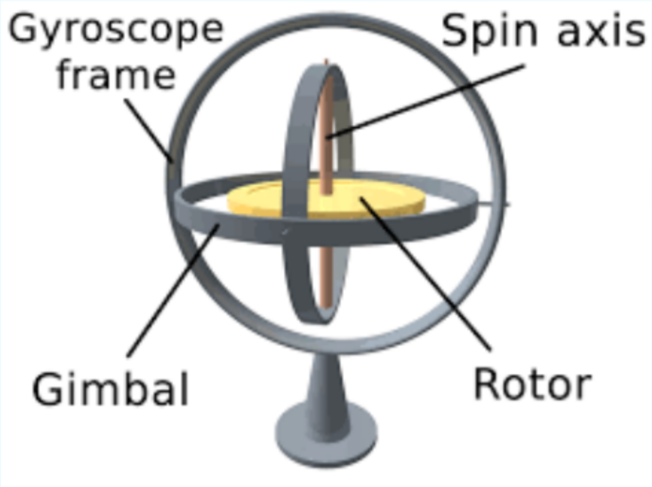

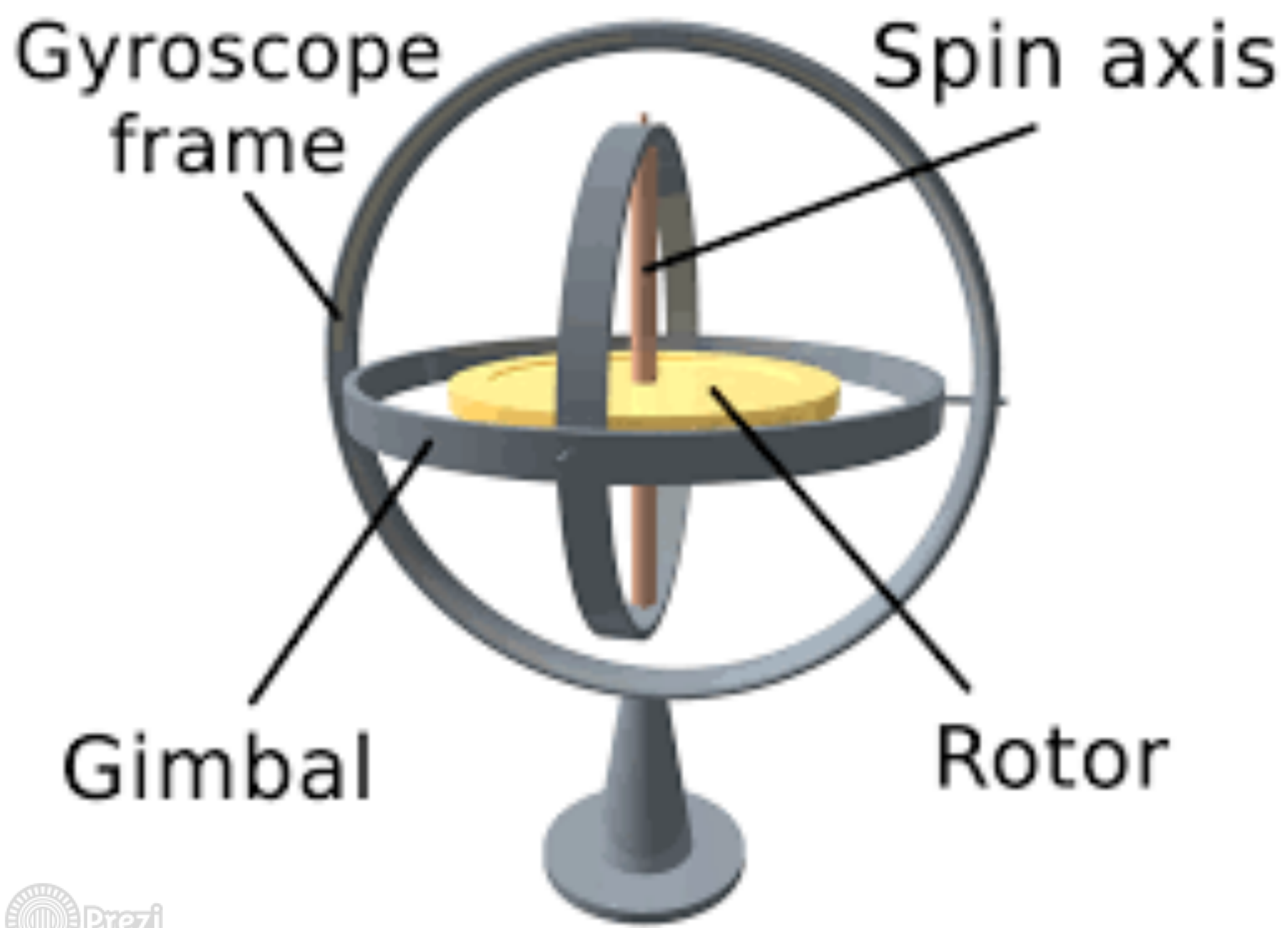
Gyroscope frame
Spin axis
Gimbal
Rotor

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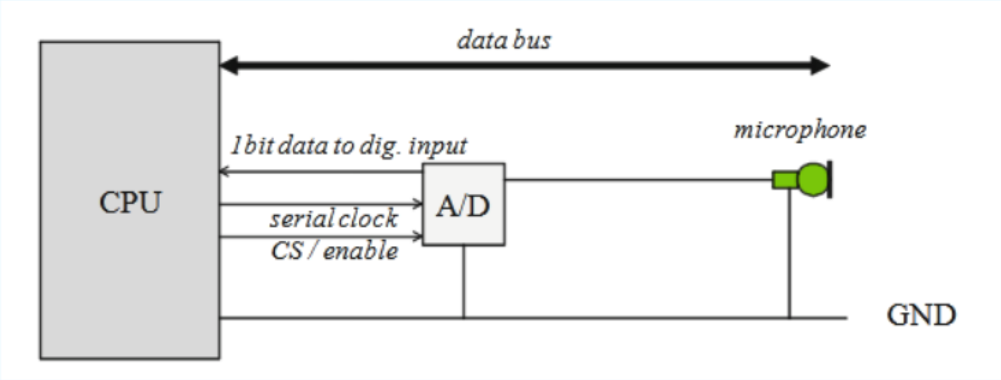
seika.de
NB43210
13841


HOLD/SOUND
CAL
ON/REF/OFF
Digital Protractor
REF
-63.58°
in/ft
RisePRO
mm/m % in/ft
LIGHT
Absolute/IP65

A/D Converter

- An A/D converter translates an analog signal into a digital value. The characteristics of an A/D converter include:
  - Accuracy expressed in the number of digits it produces per value (for example 10 bit A/D converter)
  - Speed expressed in maximum conversions per second(for example 500 conversions per second)
  - Measurement range expressed in volts (for example 0..5V)
- A/D converters come in many variations. The output format also varies.
- Typical are either a parallel interface (for example up to 8 bits of accuracy) or asynchronous serial interface.



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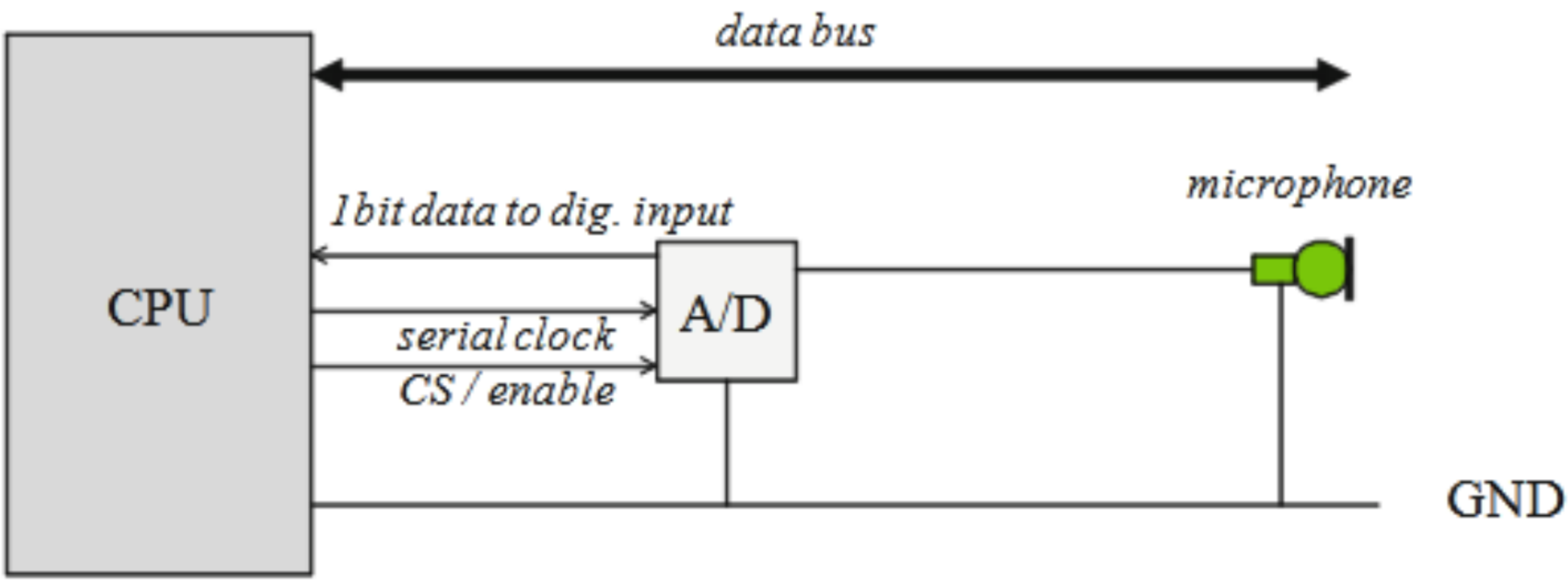
s serial interface.



- Vector 2X

Digital Camera

Digital Camera

- Digital cameras are the most complex sensors used in robotics.
- For mobile robot applications, we are interested in a high frame rate,because our robot is moving and we want updated sensor data as fast as possible.
- For most applications for small mobile robots, a resolution of 60×80 pixels is sufficient. Even from such a small resolution we can detect, for example, colored objects or obstacles in the way of a robot
- At this resolution, frame rates (reading only) of up to 30 fps(frames per second) are achievable.
- At 60×80 pixels with 3 bytes of color per pixel this amounts to 14,400 bytes. (60x80x3 = 14400 Bytes)

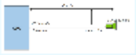
Camera Sensor Hardware

- In recent years we have experienced a shift in camera sensor technology.
- The previously dominant CCD (charge coupled device) sensor chips are now being overtaken by the cheaper to produce CMOS (complementary metal oxide semiconductor) sensor chips.
- The brightness sensitivity range for CMOS sensors is typically larger than that of CCD sensors by several orders of magnitude.
- Typical hardware interfaces for camera sensors are 16 bit parallel, 8 bit parallel, 4 bit parallel, or serial.
- In addition, a number of control signals have to be provided from the controller. Only a few sensors buffer the image data and allow arbitrarily slow reading from the controller via handshaking.
- The parameters that can be set in software vary between sensor chips.
- Most common are the setting of frame rate, image start in (x,y), image size in (x,y),brightness, contrast, color intensity, and auto-brightness.

Camera Interface

Simple Camera Interface

- The simplest camera interface to a CPU is shown in Figure below.
- The camera clock is linked to a CPU interrupt, while the parallel camera data output is connected directly to the data bus.
- Every single image byte from the camera will cause an interrupt at the CPU, which will then enable the camera output and read one image data byte from the data bus.



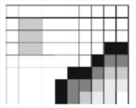
Interfacing using FIFO

- Creating one interrupt per image byte is not the best possible solution. It would be better to buffer a number of bytes and then use an interrupt much less frequently to do a bulk data transfer of image data.
- This approach using a FIFO buffer for intermediate storing of image data.
- The advantage of a FIFO buffer is that it supports un-synchronized read and write in parallel.
- So while the camera is writing data to the FIFO buffer, the CPU can read data out, with the remaining buffer contents staying undisturbed.
- The FIFO provides three additional status lines:
  - Empty flag
  - Full flag
  - Half full flag
- These digital outputs of the FIFO can be used to control the bulk reading of data from the FIFO.
- Whenever the FIFO is half full, we initiate a bulk read operation of 50% of the FIFO's contents.

Camera Sensor Data

Grayscale

- The simplest avail-able sensor chips provide a grayscale image of 120 lines by 160 columns with 1 byte per pixel.
- A value of zero represents a black pixel, a value of 255 is a white pixel,everything in between is a shade of gray.



Color Camera

- The standard technique for pixels arranged in a grid is the Bayer pattern.
- With colored filter over the pixel array, each pixel only records the intensity of a certain color component.
- For example, a pixel with a red filter will only record the red intensity at its position.
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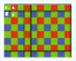
- This would result effectively in a 60×80 color image with an additional, redundant green byte per pixel.



Bayer Pattern
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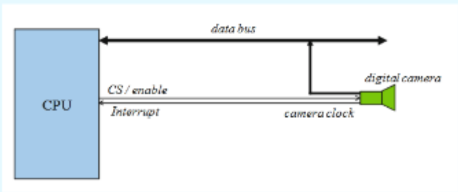

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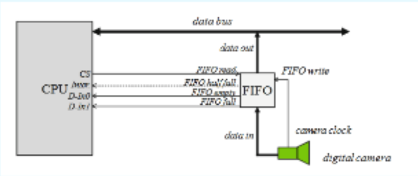

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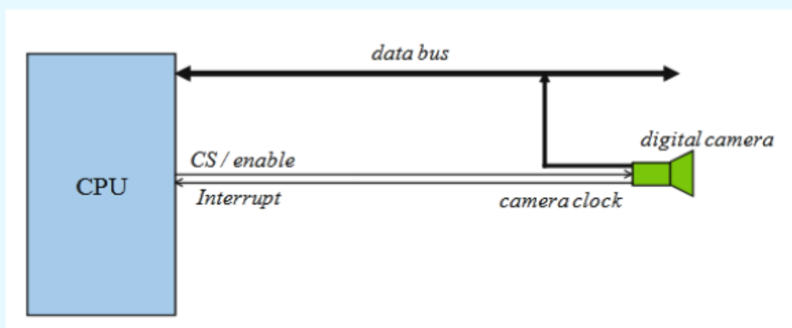

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  interru
  data.
- This a
- The ac
  write i
- So wh
  data o
- The FI
  - En
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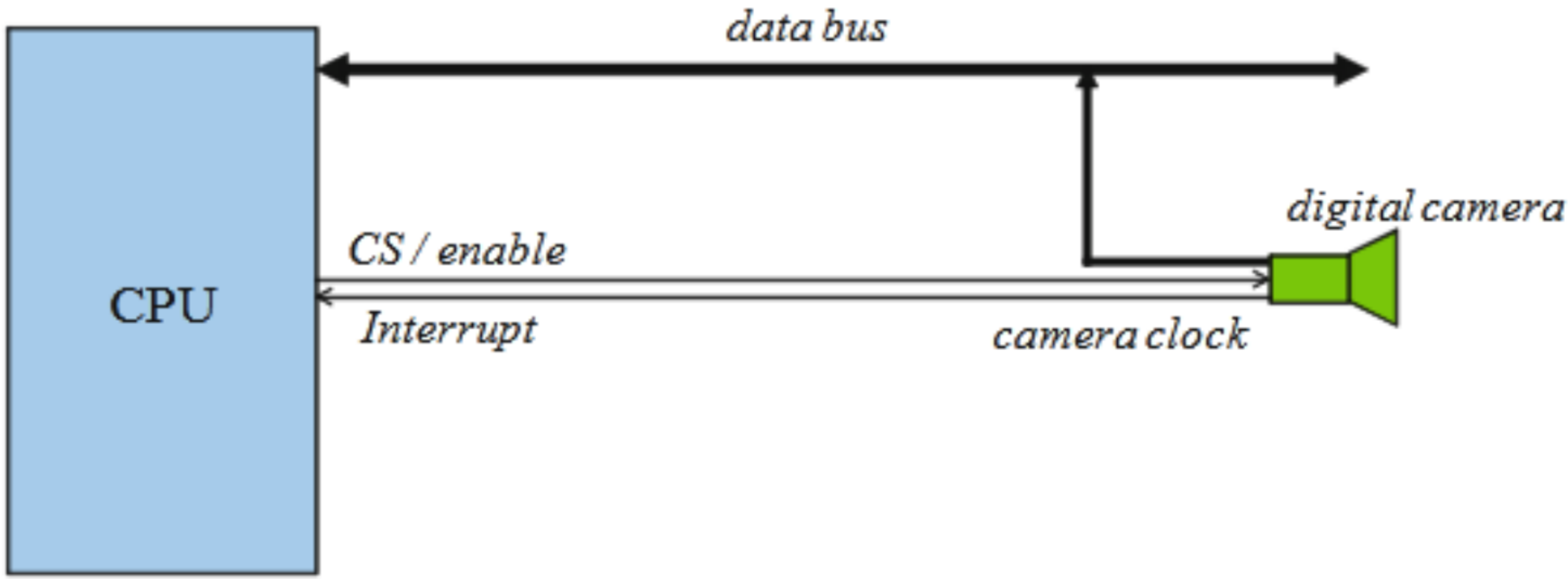
  data f
- Whene
  the FIF


data bus
CPU
CS / enable
Interrupt
digital camera
camera clock

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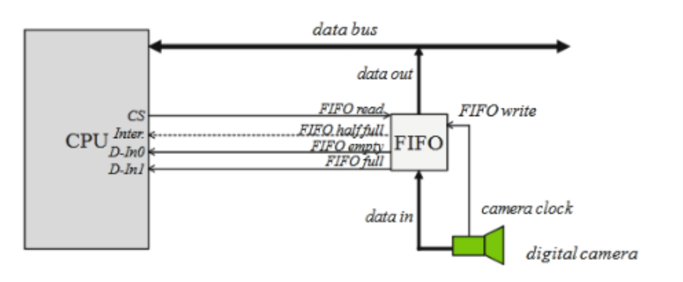
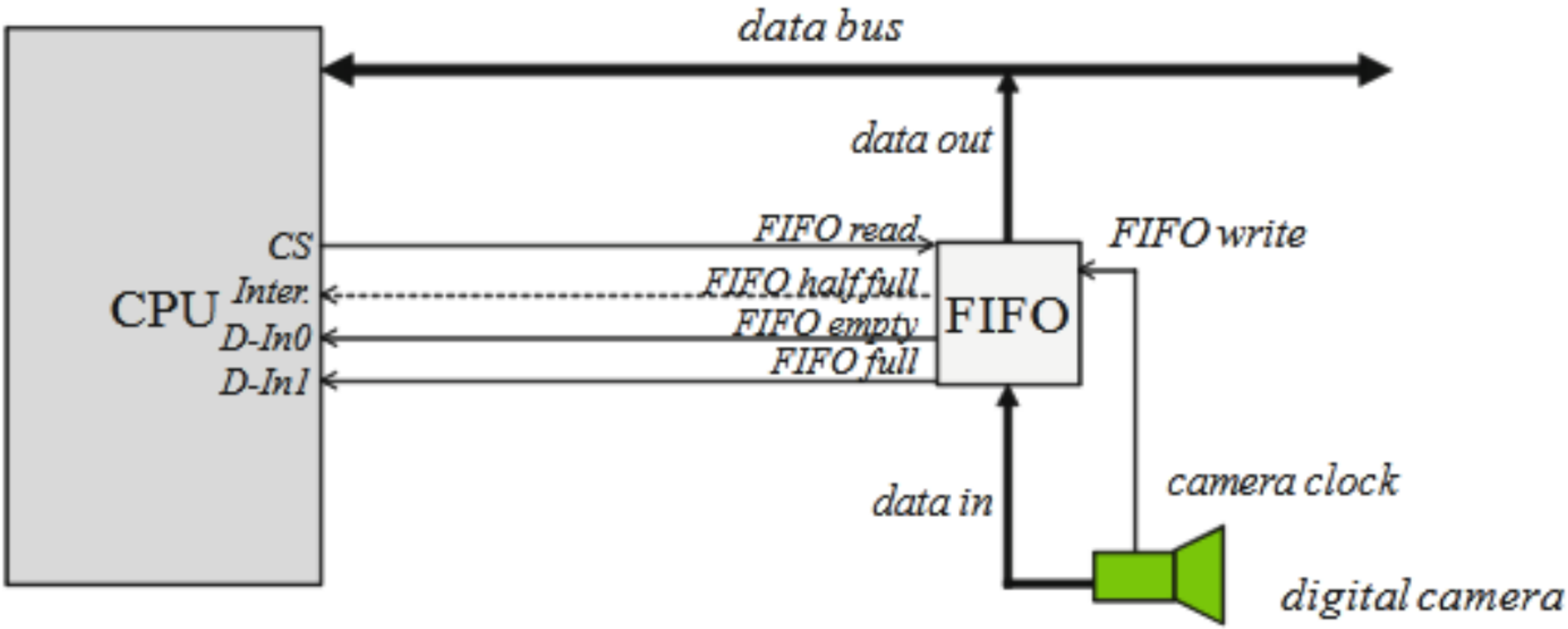


we initiate a bulk read operation of



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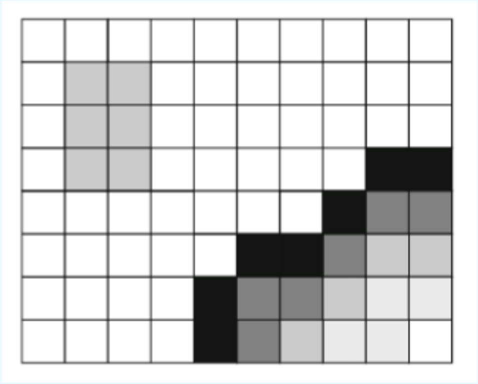

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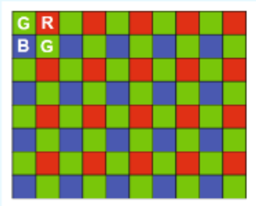

Bayer Pattern
green, red, green, red, ...
blue, green, blue, green.....

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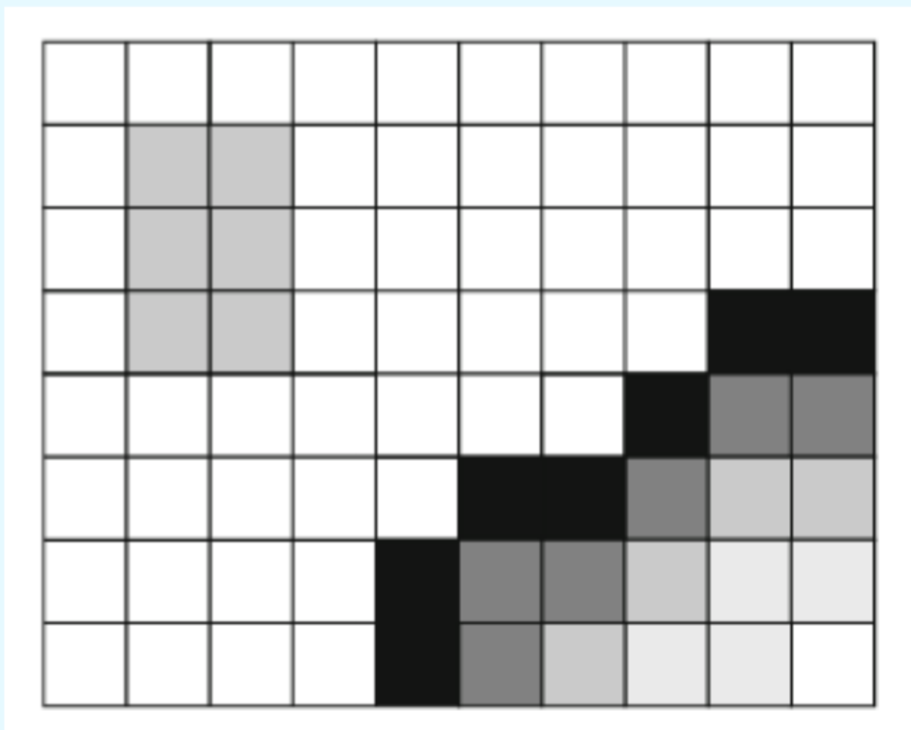

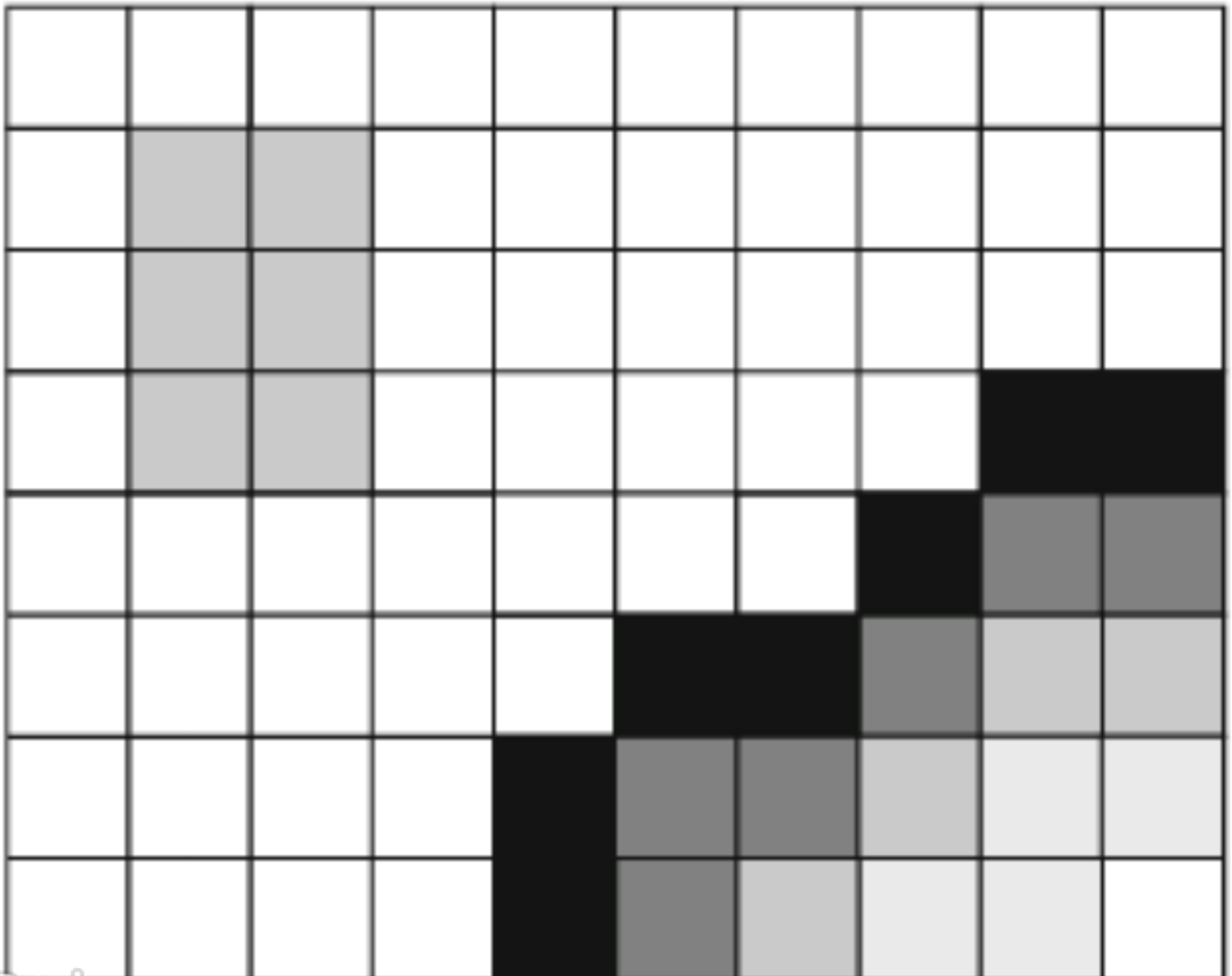

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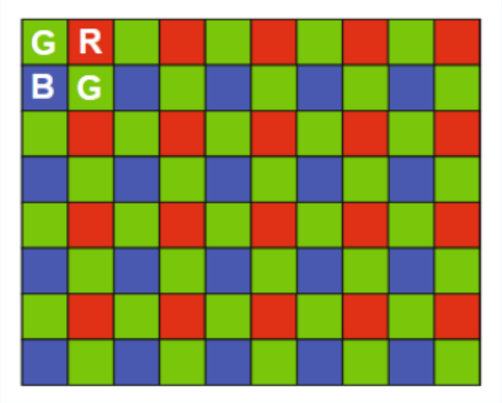

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green, red, green, red, ...
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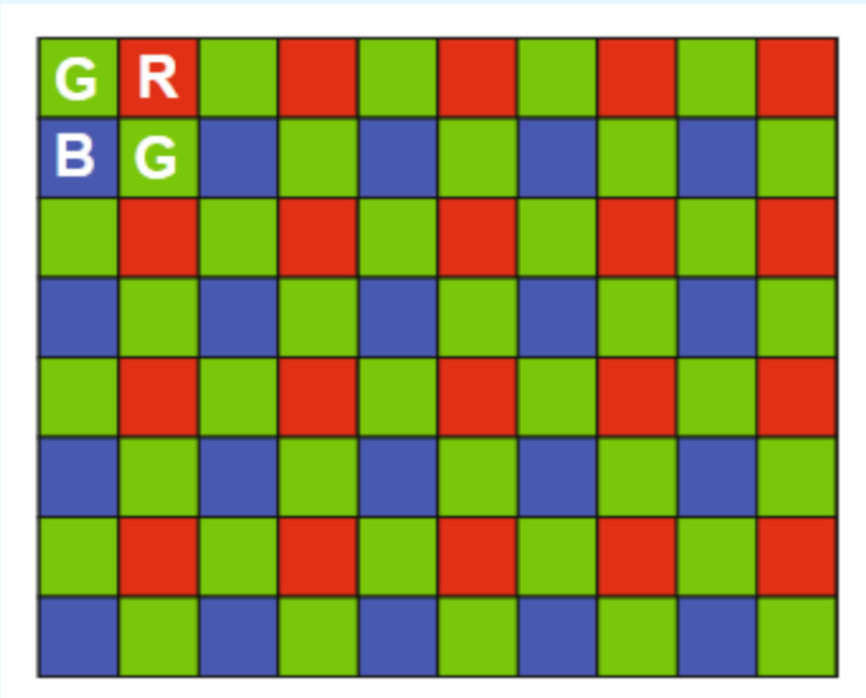

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Sensors

By Nilesh Patidar

What are sensors?

- There are a vast number of different sensors being used in robotics,applying different measurement techniques, and using different interfaces to a controller.
- The scope of this chapter is more on interfacing sensors to controllers than on understanding the internal construction of sensors themselves.
- Most important thing is to find the right sensor for a particular application. This includes-
  - right measurement technique
  - right size and weight
  - right operating temperature range and power consumption,
  - and of course the right price range.
- Data transfer from the sensor to the CPU can be either CPU-initiated (polling) or sensor-initiated (via interrupt).

Examples

Sensor Output	Sample Application
Binary signal (0 or 1)	Tactile sensor
Analog signal (e.g. 0..5V)	Inclinometer
Timing signal (e.g. PWM)	Gyroscope
Serial link (RS232 or USB)	GPS module
Parallel link	Digital camera

Sensor Categories

From a robot's point of view, it is more important to distinguish:
- Local or on-board sensors(sensors mounted on the robot)
- Global sensors (sensors mounted outside the robot in its environment and transmitting sensor data back to the robot)

For mobile robot systems it is also important to distinguish:
- Internal or proprioceptive sensors (sensors monitoring the robot's internal state)
- External sensors(sensors monitoring the robot's environment

A further distinction is between:
- Passive sensors(sensors that monitor the environment without disturbing it,for example digital camera, gyroscope)
- Active sensors(sensors that stimulate the environment for their measurement,for example sonar sensor, laser scanner, infrared sensor)

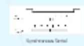
Sensors Classification

	Local	Global
Internal	**Passive** battery sensor, chip-temperature sensor, shaft encoders, accelerometer, gyroscope, inclinometer, compass **Active** –	**Passive** – **Active** –
External	**Passive** on-board camera **Active** sonar sensor, infrared distance sensor, laser scanner	**Passive** overhead camera, satellite GPS **Active** sonar (or other) global positioning system

Analog v/s Digital Sensors

A number of sensors produce analog output signals rather than digital signals. This means an A/D converter (analog to digital converter) is required to connect such a sensor to a micro controller.

Typical examples of such sensors are:
- Microphone
- Analog infrared distance sensor
- Analog compass
- Barometer sensor



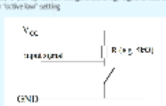
Digital sensors on the other hand are usually more complex than analog sensors and often also more accurate. In some cases the same sensor is available in either analog or digital form, where the latter one is the identical analog sensor packaged with an A/D converter.

The output signal of digital sensors can have different forms. It can be a parallel interface (for example 8 or 16 digital output lines), a serial interface (for example following the RS232 standard) or a "synchronous serial" interface.

Different Types of Sensors

Binary Sensor

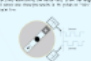
- Binary sensors are the simplest type of sensors. They only return a single bit of information, either 0 or 1.
- A typical example is a tactile sensor on a robot.
- In this case, a pull-up resistor will generate a high signal unless the switch is activated. This is called an "active low" setting.



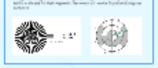
Shaft Encoder

Encoders are required as a fundamental feedback sensor for motor control. There are several techniques for building an encoder. The most widely used ones are either magnetic encoders or optical encoders.

Magnetic Encoders



Optical Encoders



Position Sensitive Device

Mobile robots have been equipped with various sensor types for measuring distances to the nearest obstacle around the robot for navigation purposes.

Sonar Sensors

Infrared Sensors

Compass

- A compass is a very useful sensor in many mobile robot applications, especially self-localization. An autonomous robot has to rely on its on-board sensors in order to keep track of its current position and orientation.
- The standard method for achieving this in a driving robot is to use shaft encoders on each wheel, then apply a method called "dead reckoning". This method starts with a known initial position and orientation, then adds all driving and turning actions to find the robot's current position and orientation.
- Unfortunately, due to wheel slippage and other factors, the "dead reckoning" error will grow larger and larger over time. Therefore, it is a good idea to have a compass sensor on-board, to be able to determine the robot's absolute orientation.
- A suitable analog compass model is:
  - Dinsmore Digital Sensor No. 1525 or 1655
- Digital compasses are considerably more complex, but also provide a much higher directional resolution. The sensor we selected for most of our projects has a resolution of 1° and accuracy of 2°, and it can be used indoors:
  - Vector 2X

Orientation Sensors

- Orientation sensors to determine a robot's orientation in 3D space are required for projects like tracked robots, balancing robots ,walking robots , or autonomous planes.
- A variety of sensors are available for this purpose, up to complex modules that can determine an object's orientation in all three axes.
- We will concentrate here on simpler sensors, most of them only capable of measuring a single dimension. Two or three sensors of the same model can be combined for measuring two or all three axes of orientation.

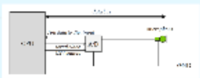
Accelerometer

Gyroscope

Inclinometer

A/D Converter

- An A/D converter translates an analog signal into a digital value. The characteristics of an A/D converter include:
  - Accuracy expressed in the number of digits it produces per value (for example 10 bit A/D converter)
  - Speed expressed in maximum conversions per second(for example 500 conversions per second)
  - Measurement range expressed in volts (for example 0..5V)
- A/D converters come in many variations. The output format also varies.
- Typical are either a parallel interface (for example up to 8 bits of accuracy) or a synchronous serial interface.



Digital Camera

Digital Camera

Camera Sensor Hardware

Camera Interface

Camera Sensor Data

Camera Driver