CE/CZ4171
Internet of Things:
Communications and Networking

Module 3
IoT Devices

Part I Outline

- Module 1: Introduction to IoT
  - A Motivating Example
  - IoT Concept
  - IoT Trend
  - IoT Applications
  - IoT Application Enablers
  - IoT Challenges
- Module 2: General Network Architecture for IoT
  - IoT Network Architecture
  - 3-Layer Model: Functional Stack, Compute Stack
  - Cloud Computing
  - Communications with Cloud: HTTP, REST, CoAP, MQTT
- Module 3: IoT Devices
  - **Sensors and Actuators**
  - Connected Smart Objects
  - IP as the IoT Network Layer
  - Information Acquisition

Sensor

Sensor measures some physical quantity and converts that measurement reading into a digital representation

- Active or passive: Sensors produce an energy output and require external power supply (active) or whether they simply receive energy and typically require no external power supply (passive)
- Invasive or non-invasive: Sensor is part of the environment it is measuring (invasive) or external to it (non-invasive)
- Contact or no-contact: Sensors require physical contact with what they are measuring (contact) or not (no-contact)

Sensor (cont'd)

- Absolute or relative: Sensors measure on an absolute scale (absolute) or based on a difference with a fixed or variable reference value (relative)
- Area of application: Sensors for specific industry or vertical/general where they are being used.
- How sensors measure: Sensors, for example, thermoelectric, electrochemical, piezoresistive, optic, electric, fluid mechanic, photoelastic.

Sensor Types

- Occupancy and motion: Ultrasonic, Radar
- Velocity and acceleration: Accelerometer, Gyroscope
- Force: Force gauge, tactile sensor (touch sensor)
- Acoustic: Microphone, hydrophone
- Humidity: Hygrometer, humistor, soil moisture sensor
- Light: Infrared sensor, photodetecror, flame detector
- Chemical sensors: Breathalyzer, smoke detector
- Biosensors: Blood glucose, pulse oximetry, electrocardiograph

Visual Sensor

Ultrasound Sensor

Infrared Sensor

Sensors on Smartphone

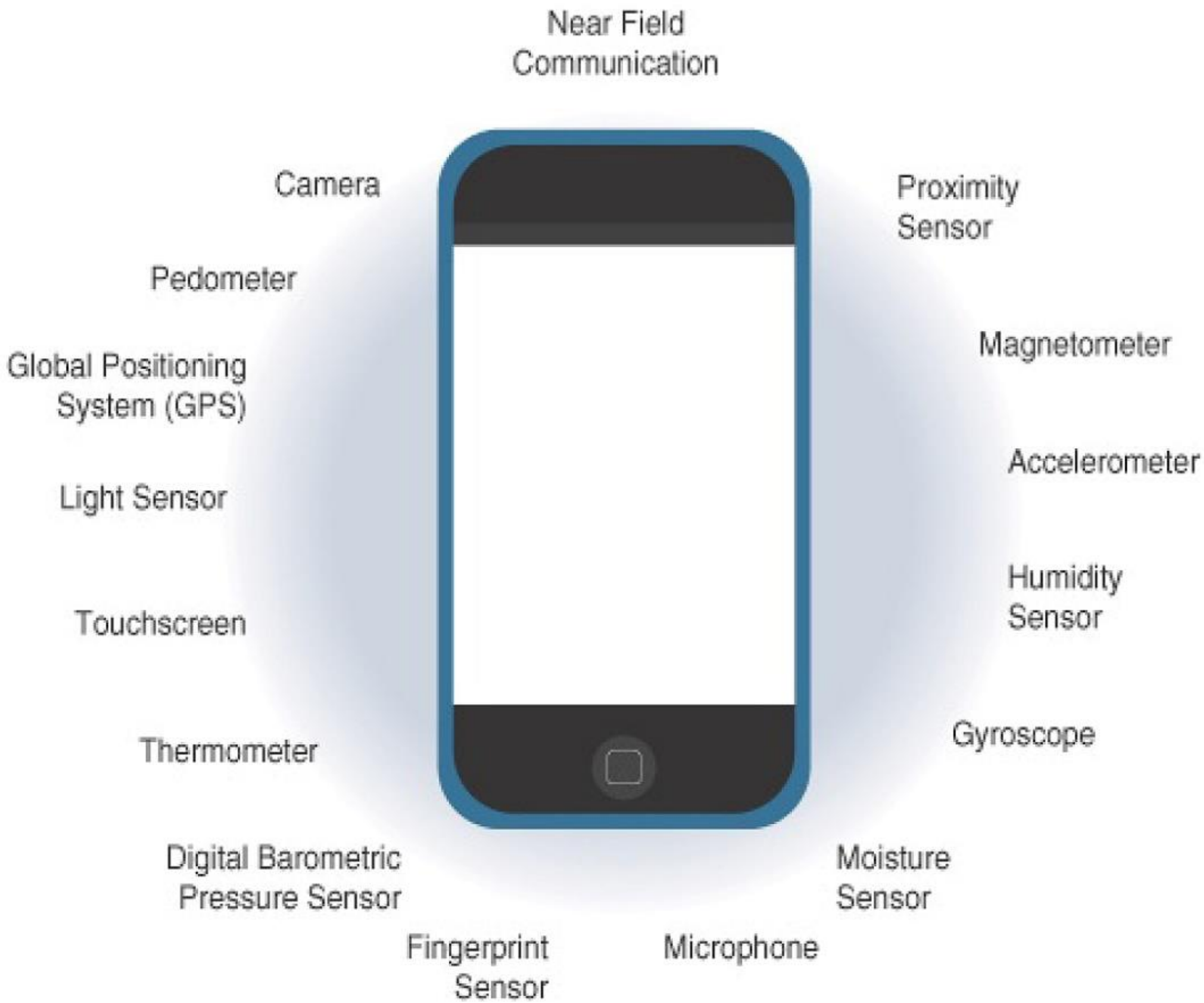


Figure 3-2 *Sensors in a Smart Phone*

Hardware Sensor vs. Software Sensor

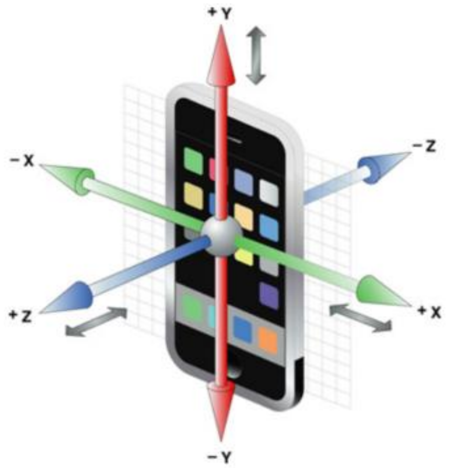
- **Hardware**-based sensors
  - Physical components built into a device
  - They derive their data by directly measuring specific environmental properties
- **Software**-based sensors
  - Not physical devices, although they mimic hardware-based sensors
  - They derive their data from one or more hardware-based sensors

Categorization of Smartphone Sensors

Sensor	Function Type	Software-based or Hardware-based
Accelerometer	Motion Sensor	Hardware-based
Gyroscope	Motion Sensor	Hardware-based
Gravity	Motion Sensor	Software-based
Rotation Vector	Motion Sensor	Software-based
Magnetic Field	Position Sensor	Hardware-based
Proximity	Position Sensor	Hardware-based
GPS	Position Sensor	Hardware-based
Digital campus	Position Sensor	Software-based
Light	Environmental Sensor	Hardware-based
Thermometer	Environmental Sensor	Hardware-based
Barometer	Environmental Sensor	Hardware-based
Humidity	Environmental Sensor	Hardware-based

Motion and Orientation Sensors

- Most of the sensors use the same **coordinate system**
- When a device's screen is facing the user
  - The X axis is horizontal and points to the right
  - The Y axis is vertical and points up
  - The Z axis pints toward outside of the screen face



Accelerometer

- Measure proper acceleration (acceleration it experiences relative to free fall)
- Units: g

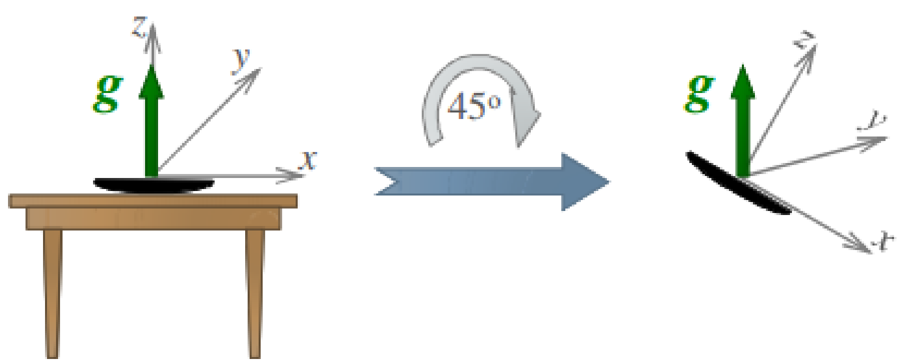
Example	G Force
Standing on earth at sea level	1g
Bugatti Veyron from 0 to 100 km/h (2.4s)	1.55g
Space Shuttle, maximum during launch and reentry	3g
Formula 1 car, peak lateral in turns	5-6g
Death or serious injury	50g
Shock capability of mechanical Omega watches	5000g

Accelerometer (cont’d)

- Acceleration is measured on 3 axes
- Note that the force of gravity is always included in the measured acceleration
  - When the device is sitting on the table stationary, the accelerometer reads a magnitude of 1g
  - When the device is in free fall, the accelerometer reads a magnitude of 0g
- To measure the real acceleration of the device, the contribution of the force of gravity must be removed from the reading, for example, by calibration

Accelerometer (cont'd)

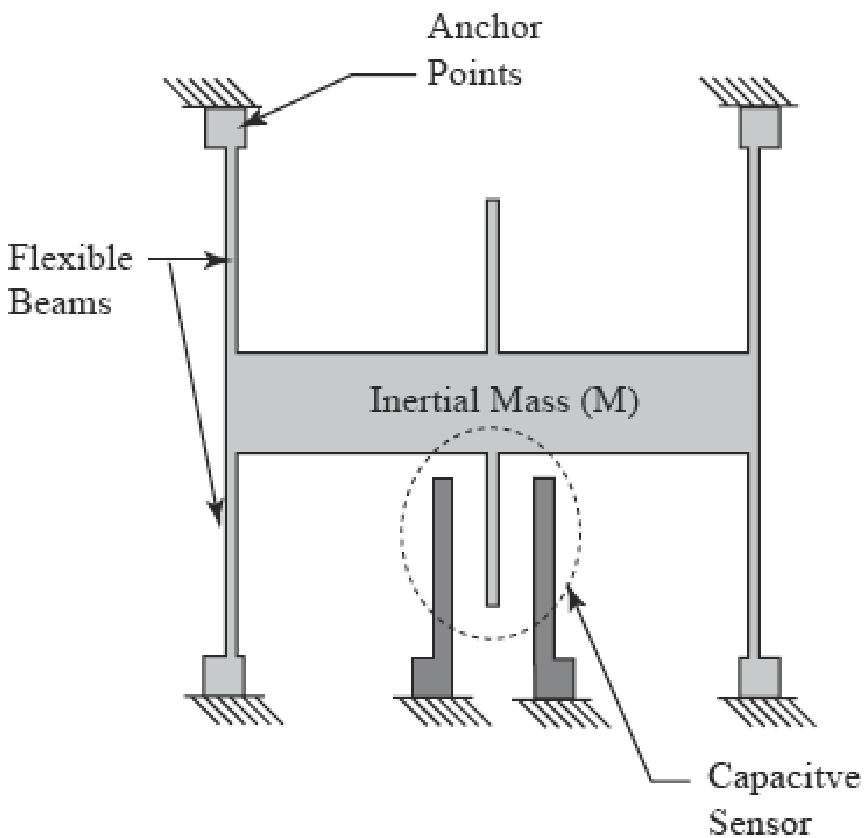
- When the device is lying flat
  - gives +1g (gravitational force) reading on Z axis
- Stationary device, after 45 degree rotation
  - Same magnitude, but rotated



$a_x = a_y = 0$
$a_z = g$

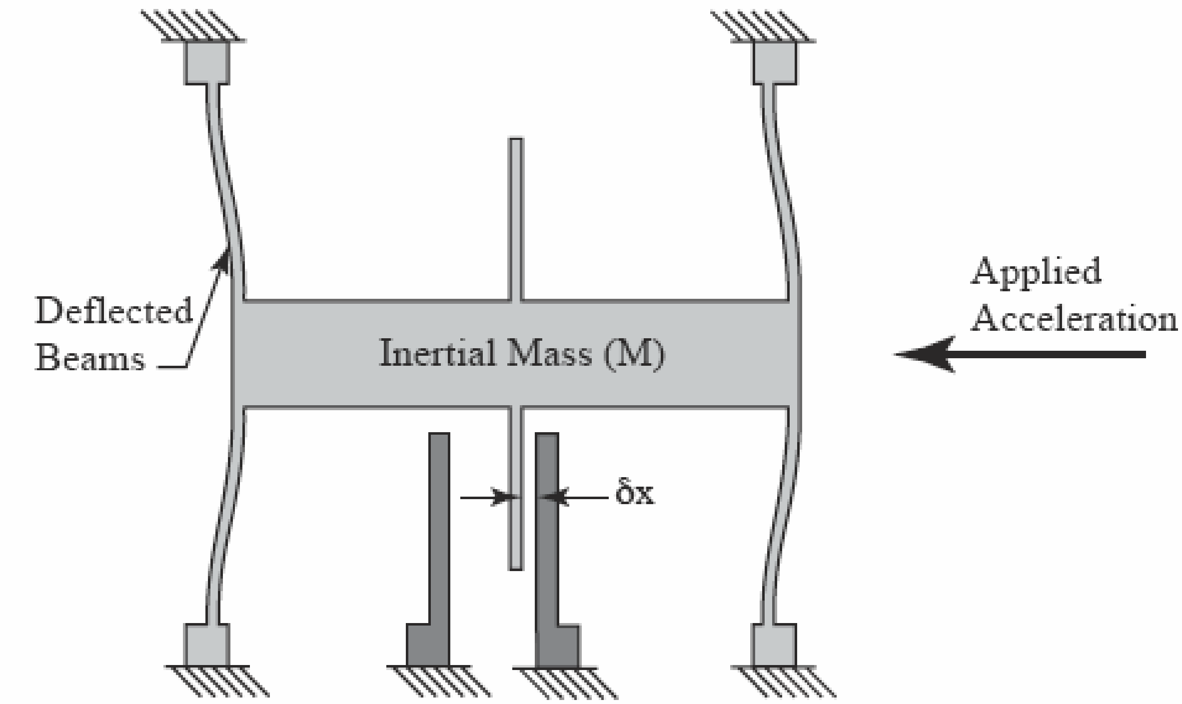
$a_y = 0$
$a_z = -a_x = g/\sqrt{2}$

Internal of Accelerometer



It consists of beams and a capacitive sensor with some anchor points

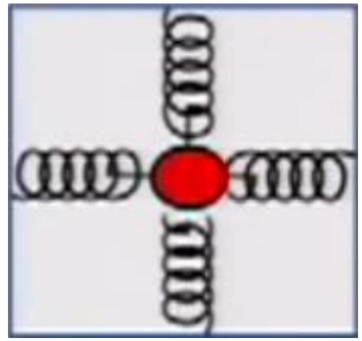
Internal of Accelerometer (cont’d)

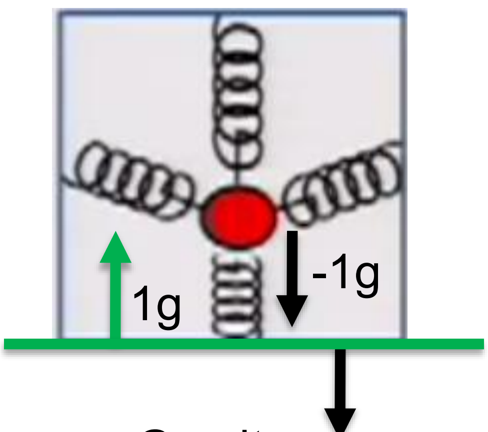


On applying the acceleration, the beams deflect and cause the change in capacitance.

Internal of Accelerometer (cont'd)

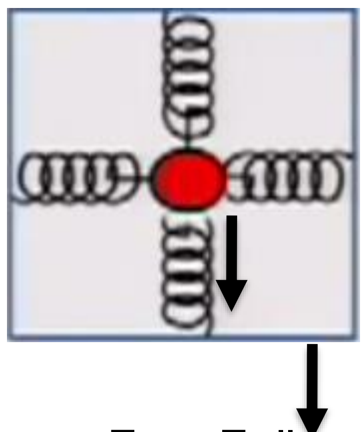
Mass on spring



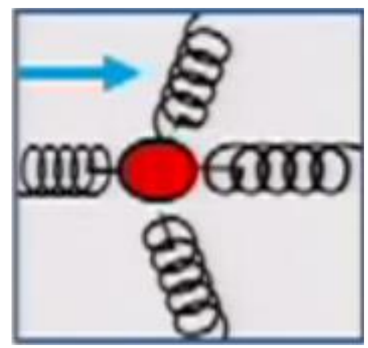


Gravity

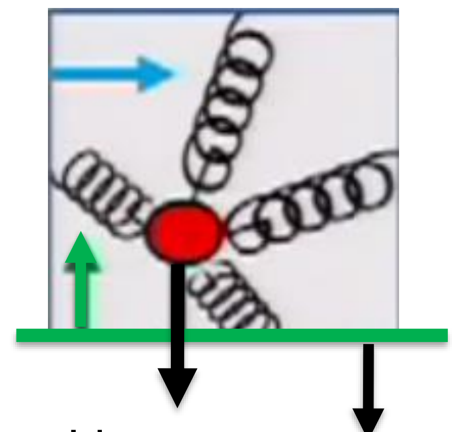
$1g = 9.8 m/s^2$



Free Fall



Linear Acceleration

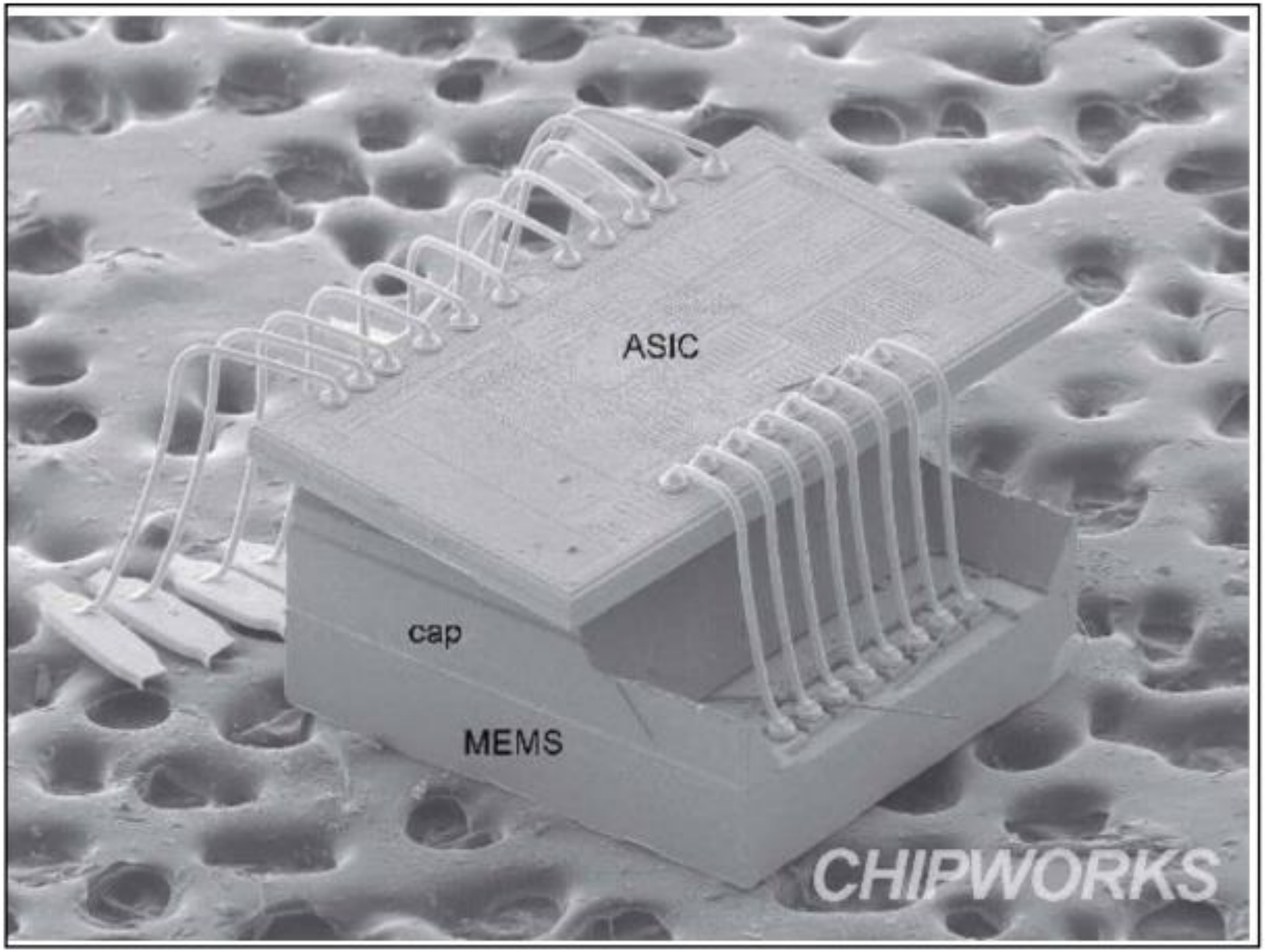


Linear Acceleration plus gravity

Smartphone: MEMS Sensors

- Micro Electro-Mechanical Systems
- Term coined in 1989
- Describes creation of mechanical elements at a scale more usually reserved for microelectronics
- MEMS use cavities, channels, cantilevers, membranes, etc. to imitate traditional mechanical systems
- Small enough to be integrated with the electronics

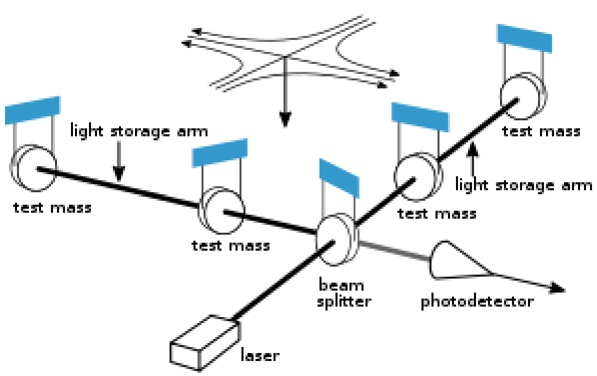
MEMS Accelerometer



Gravitational Sensor

- Gravitational sensor is not a separate hardware
- It is a virtual sensor based on the accelerometer
- It is the result when real acceleration component is removed from the reading

Gravitational-wave observatory



One arm of LIGO

LIGO

Gyroscope

- Measures the rate of rotation (angular speed) around an axis
- Speed is expressed in rad/s on 3 axis
- When the device is not rotating, the sensor values will be zeros
- It gives us 3 values
  - Pitch value (rotation around X axis)
  - Roll value (rotation around Y axis)
  - Yaw value (rotation around Z axis)

- Gyroscope is error prone over time
- As time goes, gyroscope introduces drift in result
- By sensor fusion (combining accelerometer and gyroscope), results can be corrected and path of movement of device can be obtained correctly

Accelerometer vs. Gyroscope

- Accelerometer
  – Senses linear movement: not good for rotations, good for tilt detection
  – Does not know difference between gravity and linear movement
- Gyroscope
  – Measures all types of rotations
  – Not movement
- A+G = both rotation and movement tracking possible

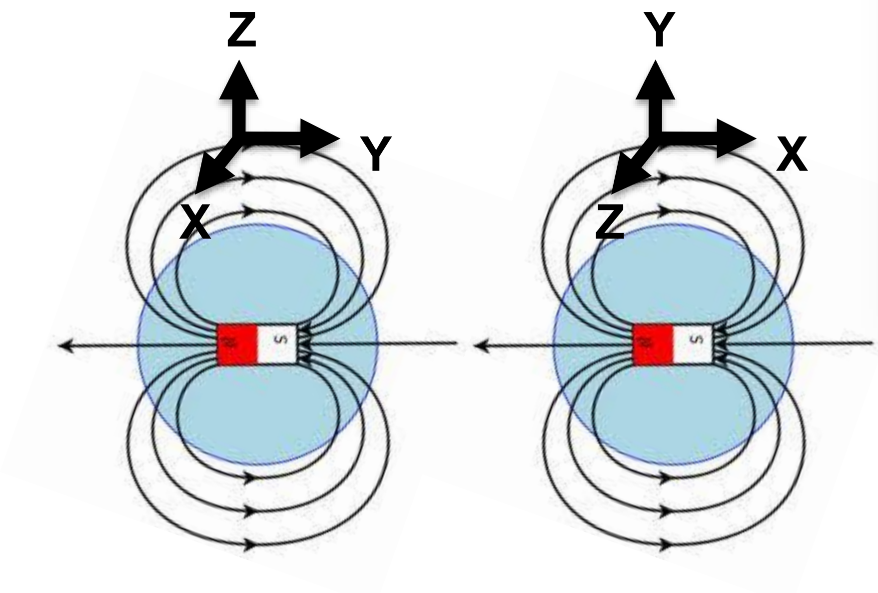
Magnetic Field Sensor (Magnetometer)

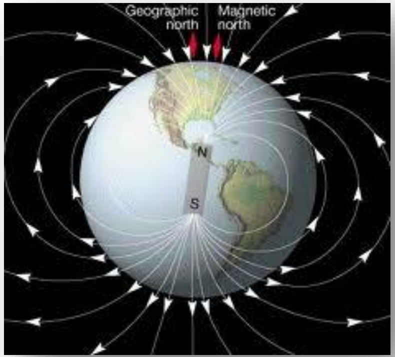
- Measures direction and strength of earth's magnetic field
- Strength is expressed in tesla (T)

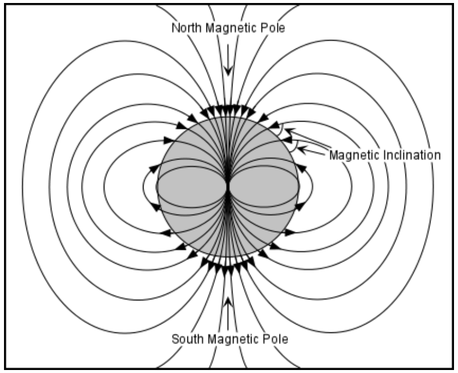
Example	Field strength
Earth's magnetic field on the equator (0° latitude)	31μT (0.00031T)
Typical fridge magnet	5mT (0.005T)
Strong neodymium magnet	1.25T
MRI system	1.5T – 3T

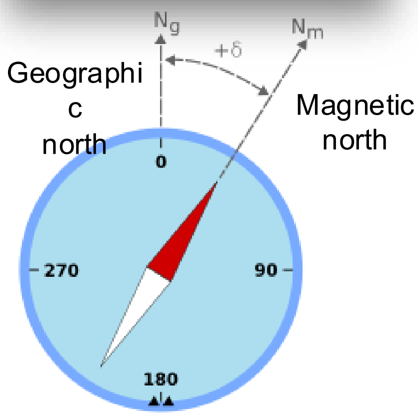
Digital Compass

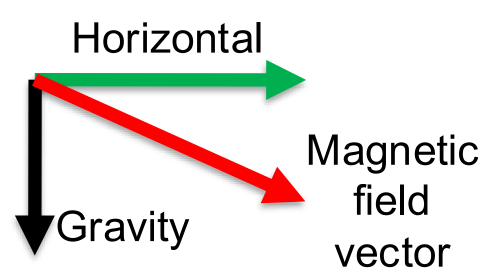
- Determine orientation
  - A software sensor based on magnetic field sensor











Magnetic declination

Magnetic inclination

Actuator

- Actuators receive some type of control signal (commonly an electric signal or digital command) that triggers a physical effect, some type of motion, force, and so on.

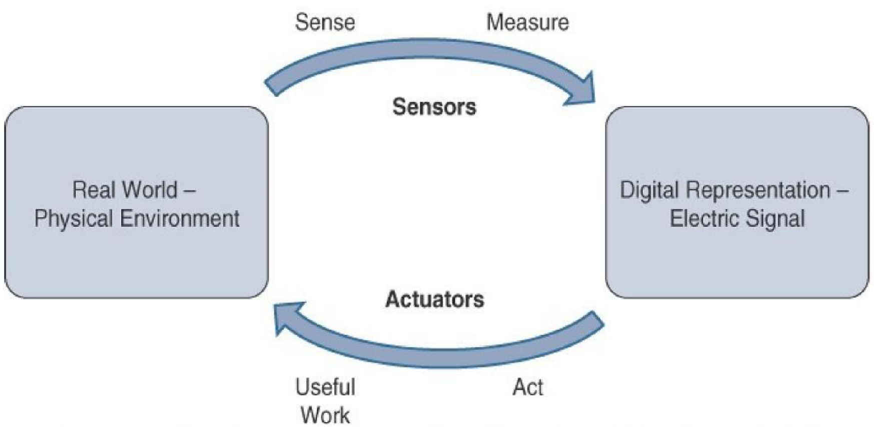


Figure 3-4 *How Sensors and Actuators Interact with the Physical World*

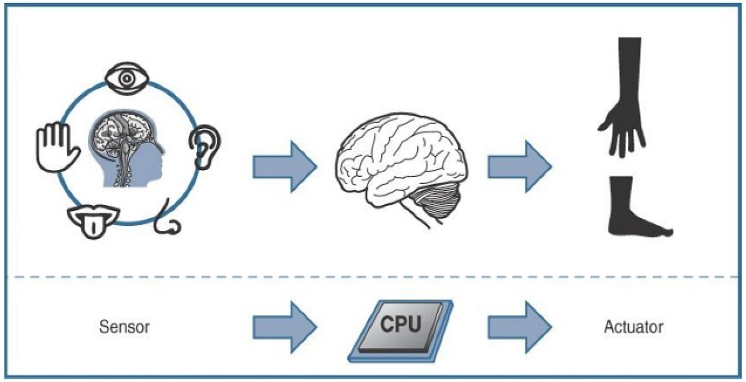
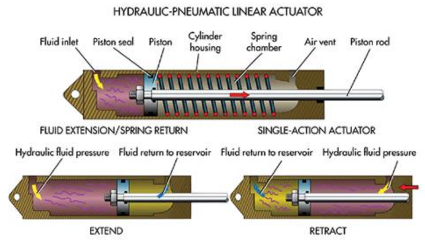


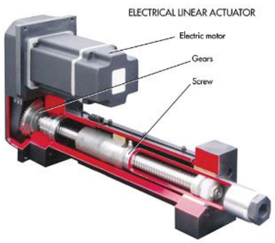
Figure 3-5 *Comparison of Sensor and Actuator Functionality with Humans*

Actuator (cont'd)

Type	Examples
Mechanical actuators	Lever, screw jack, hand crank
Electrical actuators	Thyristor, biopolar transistor, diode
Electromechanical actuators	AC motor, DC motor, step motor
Electromagnetic actuators	Electromagnet, linear solenoid
Hydraulic and pneumatic actuators	Hydraulic cylinder, pneumatic cylinder, piston, pressure control valves, air motors
Smart material actuators (includes thermal and magnetic actuators)	Shape memory alloy (SMA), ion exchange fluid, magnetorestrictive material, bimetallic strip, piezoelectric bimorph
Micro- and nanoactuators	Electrostatic motor, microvalve, comb drive

Table 3-2 *Actuator Classification by Energy Type*





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