Robotics: Principles and Practice

Module 1: Introduction and Robot Components

Lecture 3: Physical embodiment; sensors

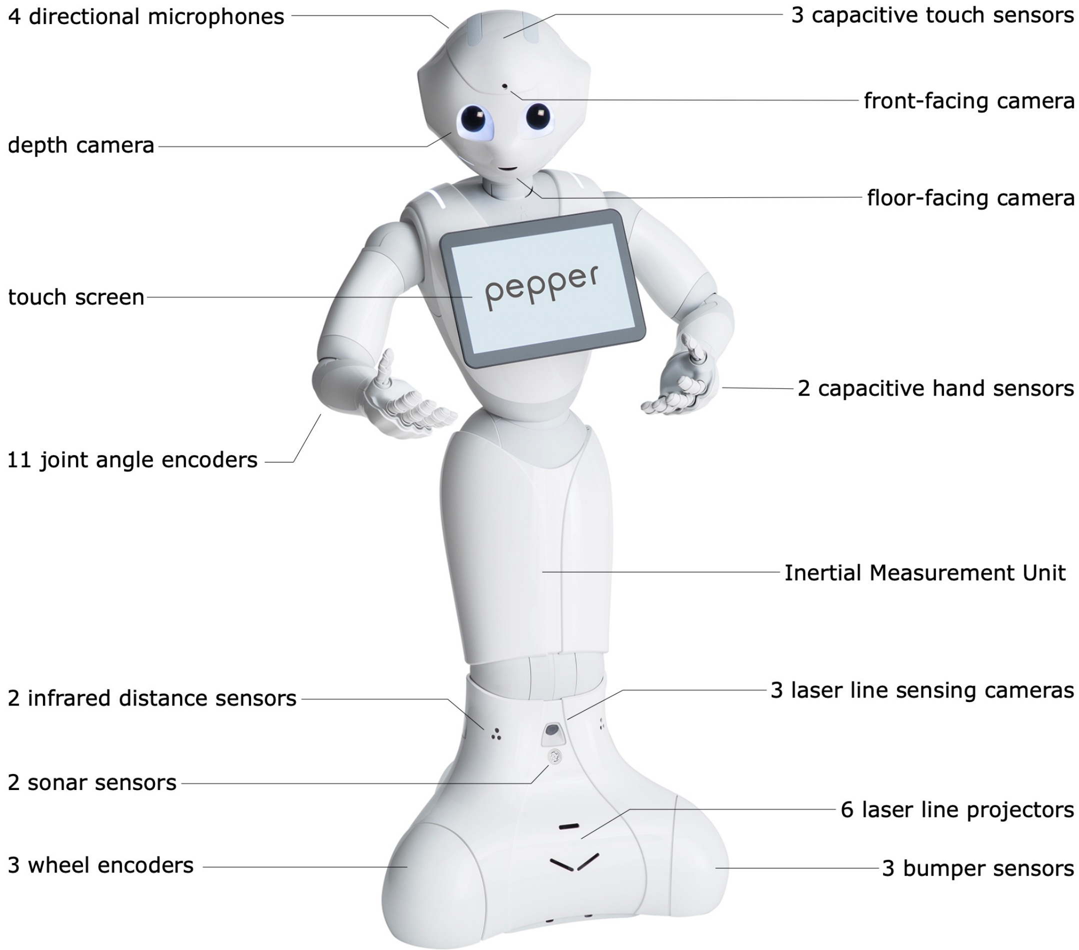
David Vernon
Carnegie Mellon University Africa

www.vernon.eu

Robot Components

- Physical embodiment
- Sensors — To perceive the environment
- Actuators
- Effectors

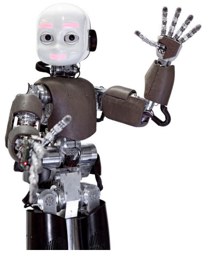
  } To take action
- Controllers — For autonomy

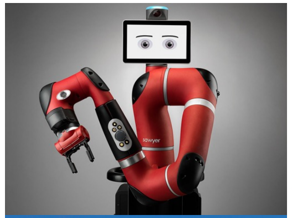
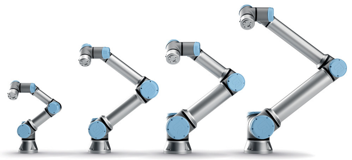


C. Bartneck, T. Belpaeme, F. Eyssel, T. Kanda, M. Keijsers, S. Šabanović, Human-Robot Interaction – An Introduction, Cambridge University Press, 2020

Physical Embodiment

- Humanoid vs non-humanoid
- Manipulator arms
- Mobile robots
- Mobile manipulators



Physical Embodiment

- Must obey physical laws
  - Can't change shape and size arbitrarily
  - Needs actuators and effectors to move around and change things in the environment
  - Needs a source of energy
- Needs to avoid unintended collisions
- The body imposes physical limitations on forms of interaction
- The body imposes temporal constraints
  - Takes time to speed up and slow down

Sensors

- Differentiate between
  - proprioceptive sensors that sense the state of the robot (proprioception)
    - Internal state, as the robot perceives it
  - exteroceptive sensors that sense the state of the environment (exteroception)
    - External state, as the robot perceives it
- The set of all possible states is referred to as the state space (discrete or continuous)

Sensors

Internal state can be used to remember information about the environment

- Representation
- Also known as internal model

Sensors

Different modalities

- Visual
- Auditory
- Olfactory (smell)
- Tactile (touch)
- Proximity (distance)

Sensors

- Joint angle & angular velocity encoders
- Joint torque sensor
- Inertial Measurement Unit (IMU) accelerometer and gyroscope sensors

Proprioceptive sensors

- RGB video cameras
- Depth cameras
- RGB-D cameras
- Microphone audio sensors
- Capacitive touch sensors
- Laser distance sensors
- Ultrasonic distance sensors
- Bumper touch sensors

Exteroceptive sensors

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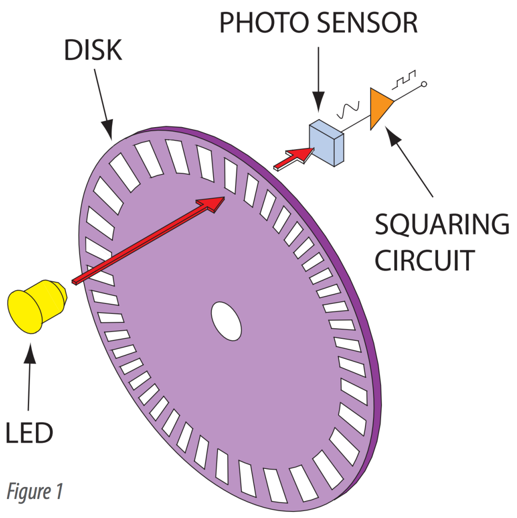

Figure 1

Source: http://encoder.com/core/files/encoder/uploads/files/WP-2011.pdf

Go to http://encoder.com/videos/
to watch a video explaining the operation of encoders

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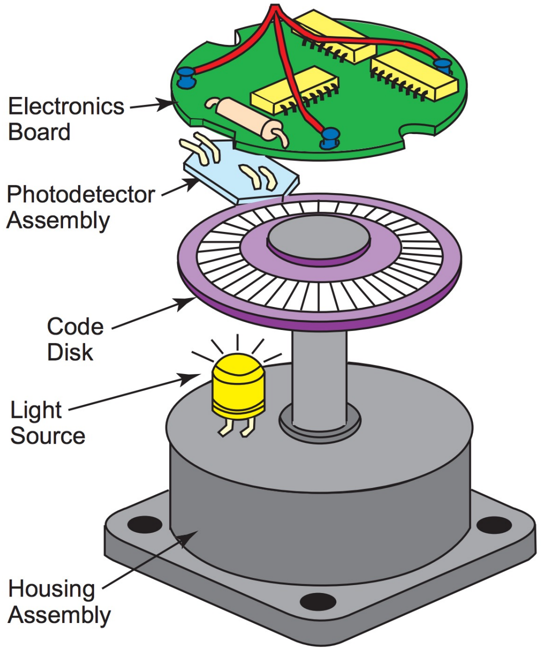

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Video

http://encoder.com/videos/

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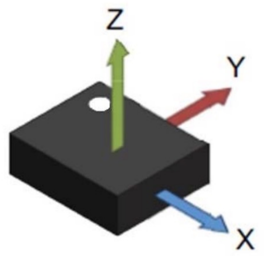
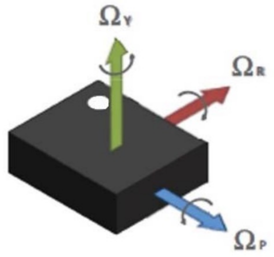
Accelerometers sense change in position
Gyroscopes sense change in orientation



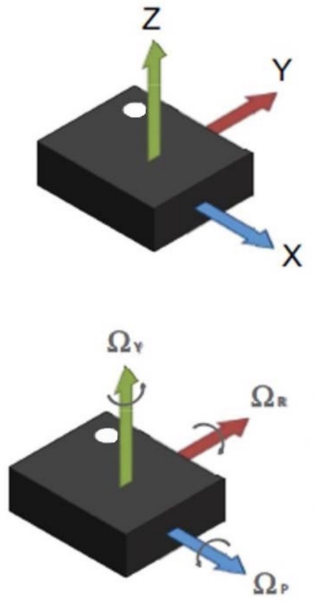


Source: https://www.st.com/resource/en/datasheet/asm330lhh.pdf

Sensors

Inertial Measurement Unit IMU

- Combines three accelerometers and three gyroscopes
- In three orthogonal (x, y, z) directions
- To sense change in position and orientation

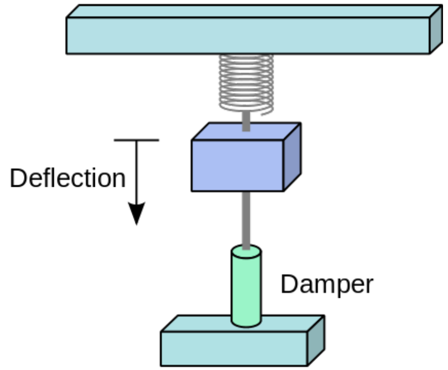


Source: https://www.st.com/resource/en/datasheet/asm330lhh.pdf

Sensors

Accelerometer

- Acceleration causes a deflection of a mass
- An open-loop accelerometer senses the deflection of the mass
  - Acceleration is determined from
    the displacement, mass, and spring constant
- A closed-loop accelerometer counteracts the force on the mass, canceling the motion
  - Acceleration is determined from the counteracting force

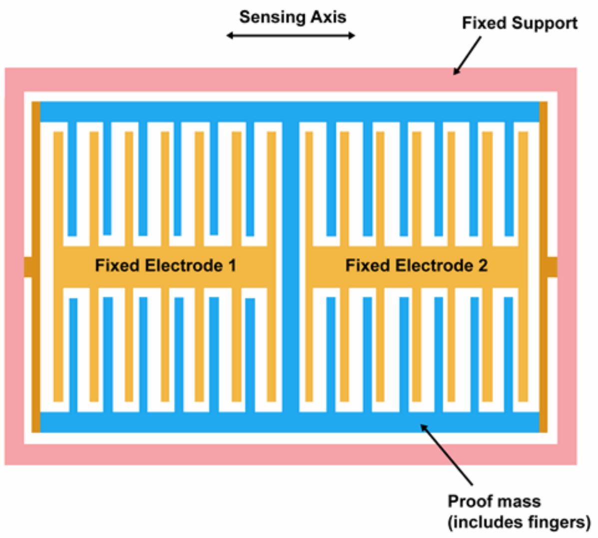


Source: https://en.wikipedia.org/wiki/Inertial_navigation_system

Sensors

Accelerometer

- Miniature microelectromechanical systems (MEMS) accelerometer
- When the sensor is subjected to a linear acceleration along its sensing axis
  - The proof mass and its fingers become displaced with respect to the fixed electrode fingers
  - The differential capacitance between the moving and fixed silicon fingers is measured
  - This is proportional to the acceleration



Source: https://www.siliconsensing.com/technology/mems-accelerometers/

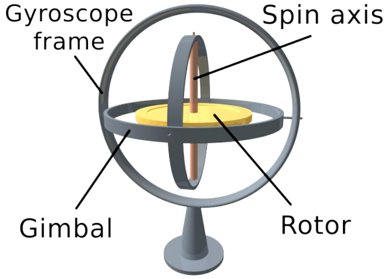
Sensors

Gyroscope

- A gyroscope is used for measuring or maintaining orientation and angular velocity

- Rate gyros measure angular rate of change of rotation

  Change in orientation is computed by integration



Source: https://en.wikipedia.org/wiki/Gyroscope

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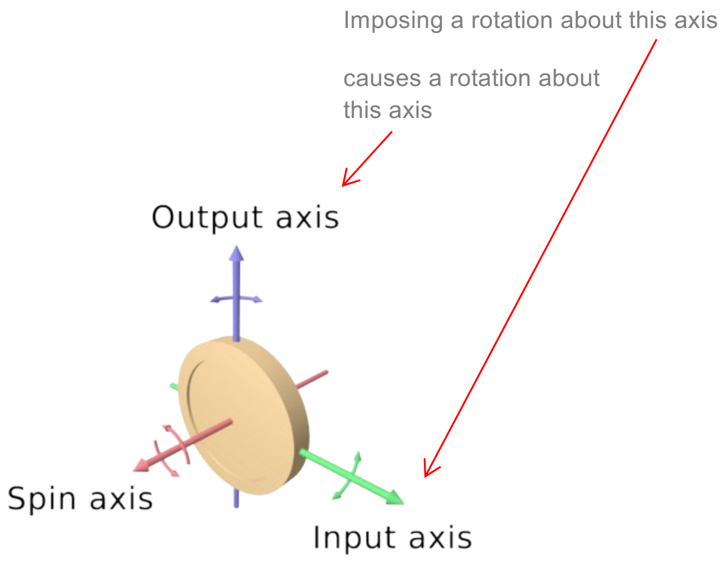

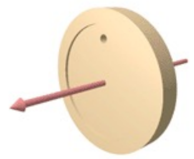

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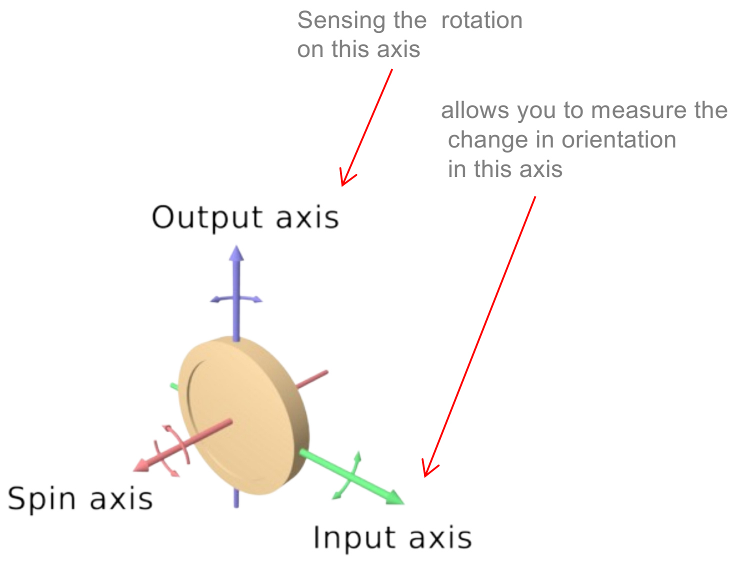
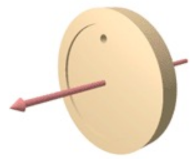




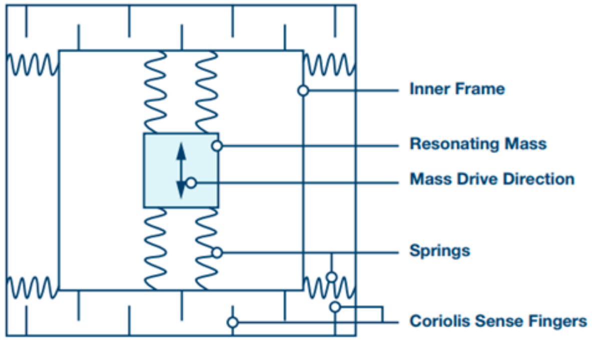
Source: https://en.wikipedia.org/wiki/Gyroscope

Sensors

Gyroscope

- Miniature microelectromechanical systems (MEMS) gyroscope

- One approach is to use a vibrating mass and the resultant displacement in an orthogonal direction to sense the rotation

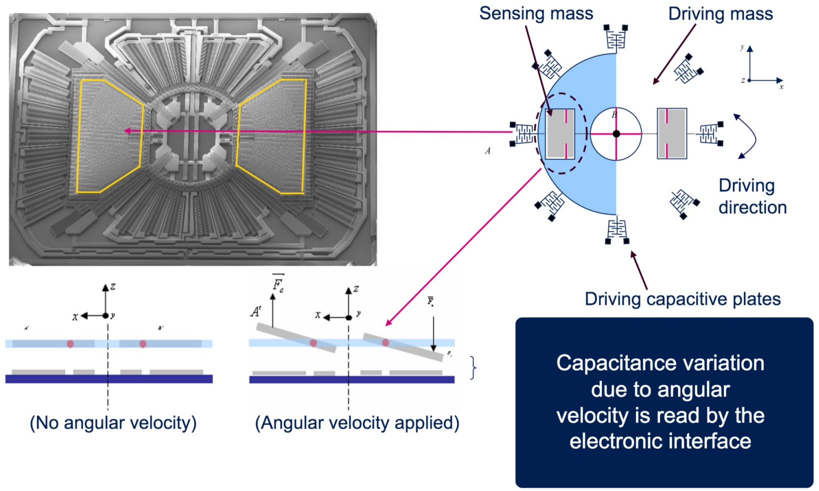


Source: https://www.analog.com/en/technical-articles/mems-gyroscope-provides-precision-inertial-sensing

Sensors

Gyroscope

- Miniature microelectromechanical systems (MEMS) gyroscope
- Others use capacitive sensing of a displaced mass to measure the rotation (angular velocity)



Source: https://www.st.com/en/mems-and-sensors/gyroscopes.html

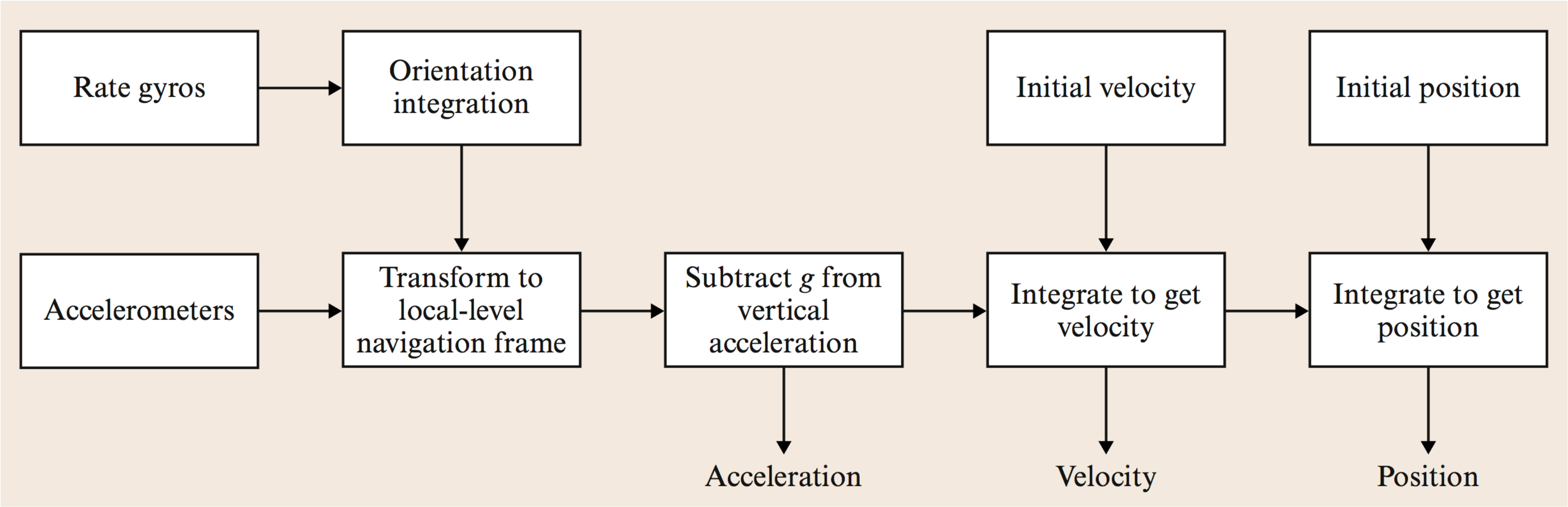
Sensors

Options for detecting change in relative position:

- Accelerometers sense acceleration … we want change in position
- Gyroscopes sense rate of change of orientation … we want change in orientation
- We get what we want by integrating the sensed data with respect to time

Sensors

Block diagram for estimating position with an IMU



Source: B. Siciliano and O. Khatib (eds.), Springer Handbook of Robotics, Springer, 2008.

Sensors

Double integration of acceleration to determine position

Ideally, the position x of a body at any time t can be determined from the time-dependent acceleration of that body

$$x(t) = \int_0^t \int_0^t a(t)\,dt\,dt + \int_0^t v_0\,dt + x_0$$

Position

Acceleration of the object: measured by the accelerometer

Initial velocity of the object

Initial position of the object

Source: https://d10bqar0tuhard.cloudfront.net/en/document/AN013-Position-determination-using-Accelerometers.pdf

Sensors

- Precise estimate if
  - initial estimate of v_0 and s_0 are precise
  - measurement of $a(t)$ is precise
- However, sensors are not perfect: errors arise
- Errors accumulate without bounds
  - Double integration means that the errors grow quadratically
  - Need to reset the position from time to time, e.g., using absolute position estimation

For more information on how to minimize errors with a MEMS accelerometer, see the technical note here: https://d10bqar0tuhard.cloudfront.net/en/document/AN013-Position-determination-using-Accelerometers.pdf

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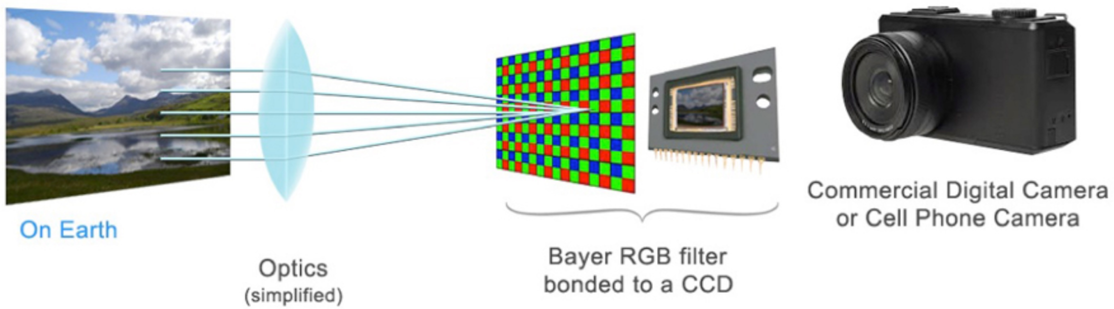

Chttps://www.nasa.gov/mission_pages/msl/multimedia/pia16799.html

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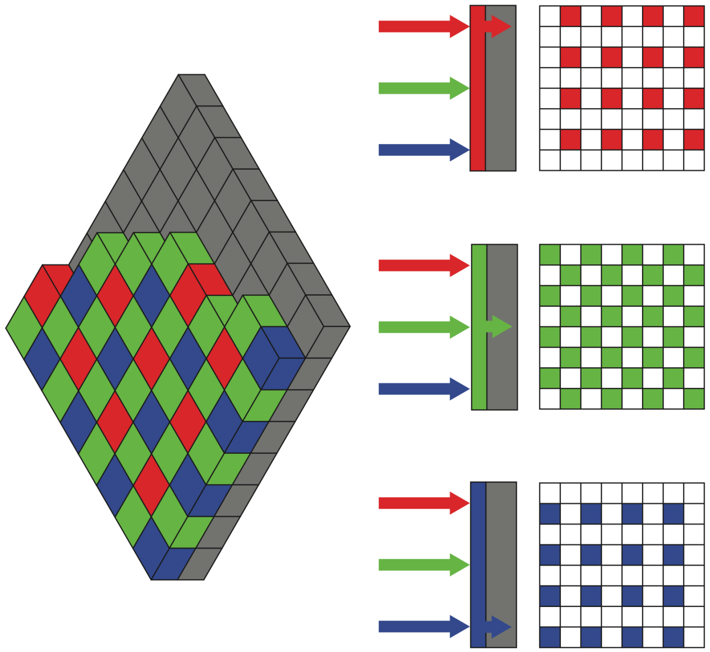

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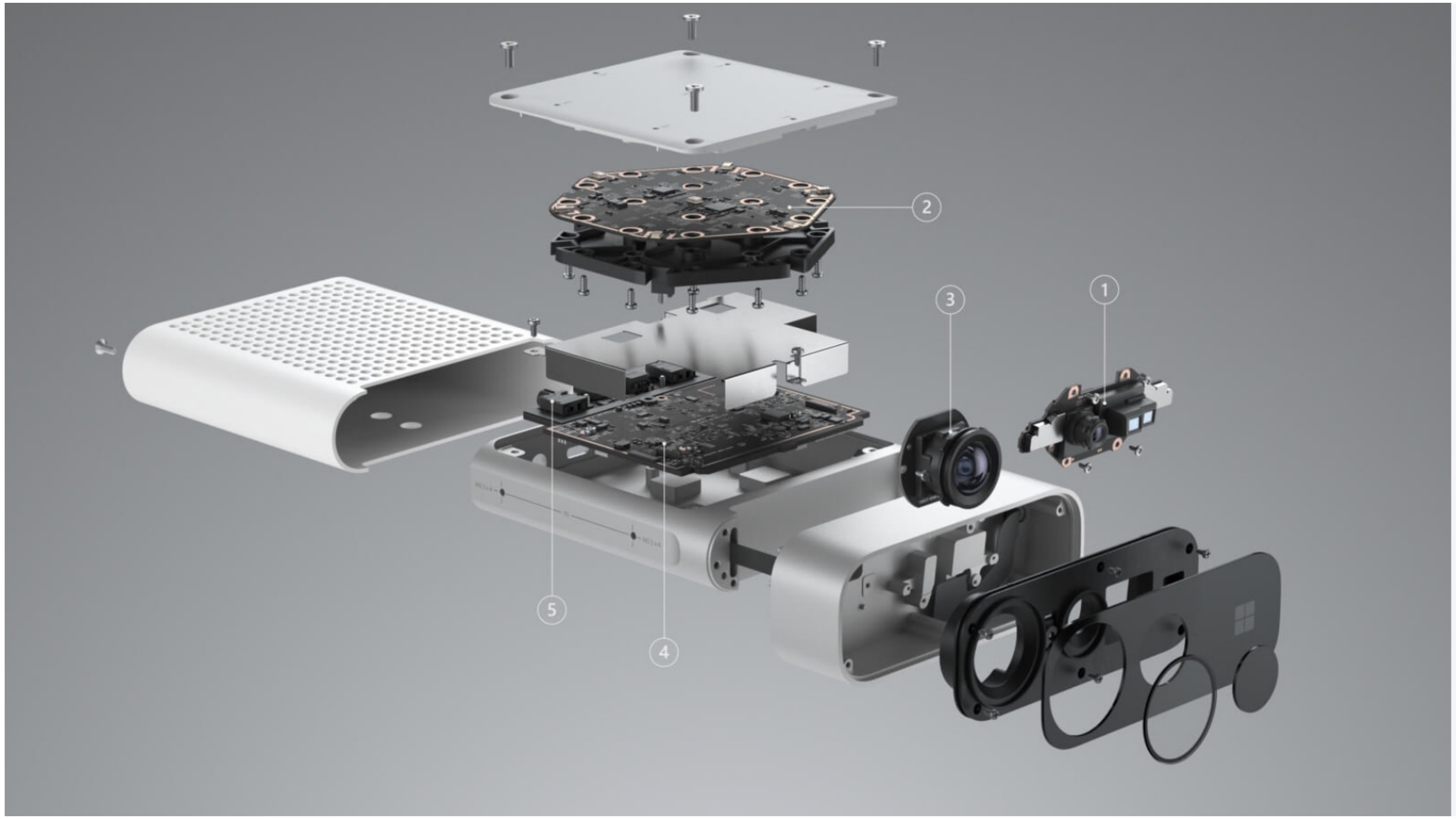
The Microsoft Azure Kinect DK sensor

https://azure.microsoft.com/en-us/topic/mixed-reality/#demystifying

Sensors



1. 1-MP depth sensor with wide and narrow field-of-view (FOV) options that help you optimize for your application
2. 7-microphone array for far-field speech and sound capture
3. 12-MP RGB video camera for an additional color stream that's aligned to the depth stream
4. Accelerometer and gyroscope (IMU) for sensor orientation and spatial tracking
5. External sync pins to easily synchronize sensor streams from multiple Kinect devices

https://azure.microsoft.com/en-us/services/kinect-dk/#industries

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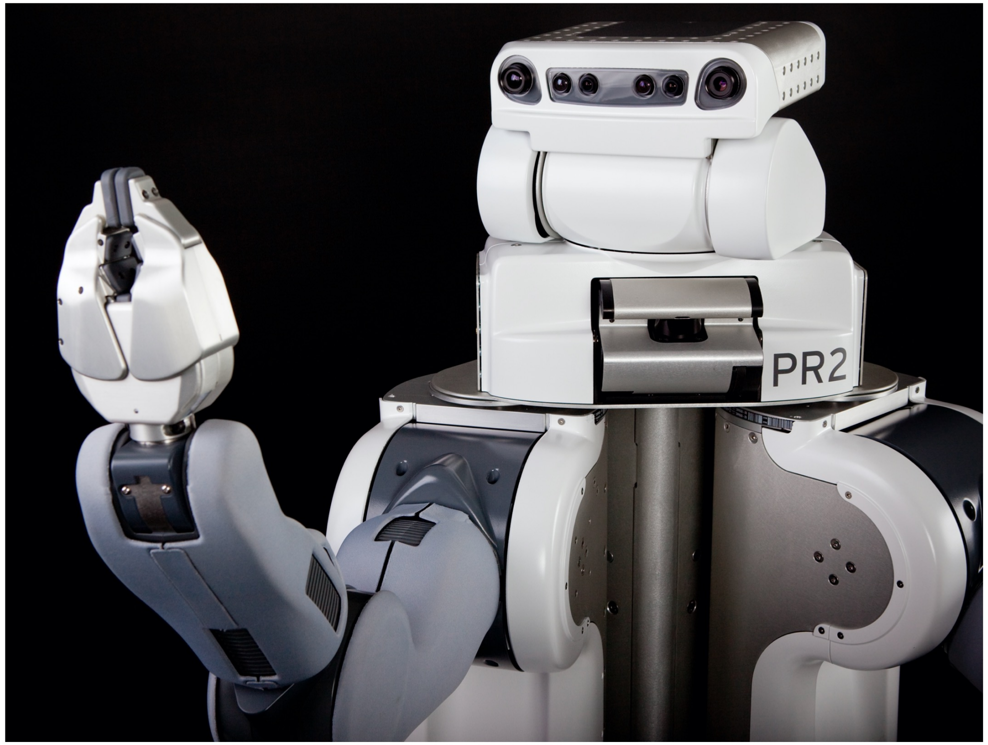

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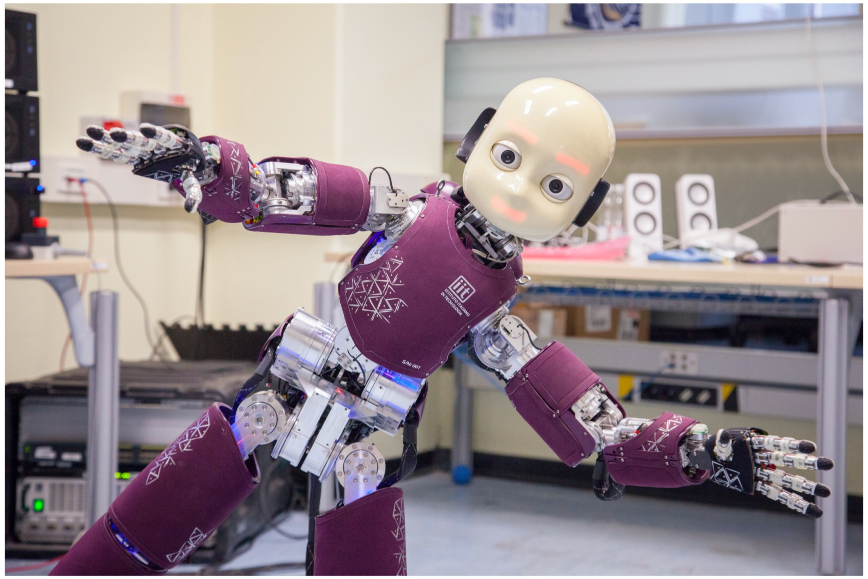

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Reading

C. Bartneck, T. Belpaeme, F. Eyssel, T. Kanda, M. Keijsers, S. Šabanović, Human-Robot Interaction – An Introduction, Cambridge University Press, 2020. Chapter 3: How a Robot Works.

https://www.human-robot-interaction.org/download/170/

M. Mataric, The Robotics Primer, MIT Press, 2007. Chapter 3.

Videos

Encoders (5:14): http://encoder.com/videos/