Introduction to Cognitive Robotics

Module 3: Mobile Robots

Lecture 3: Relative position estimation using inertial sensors

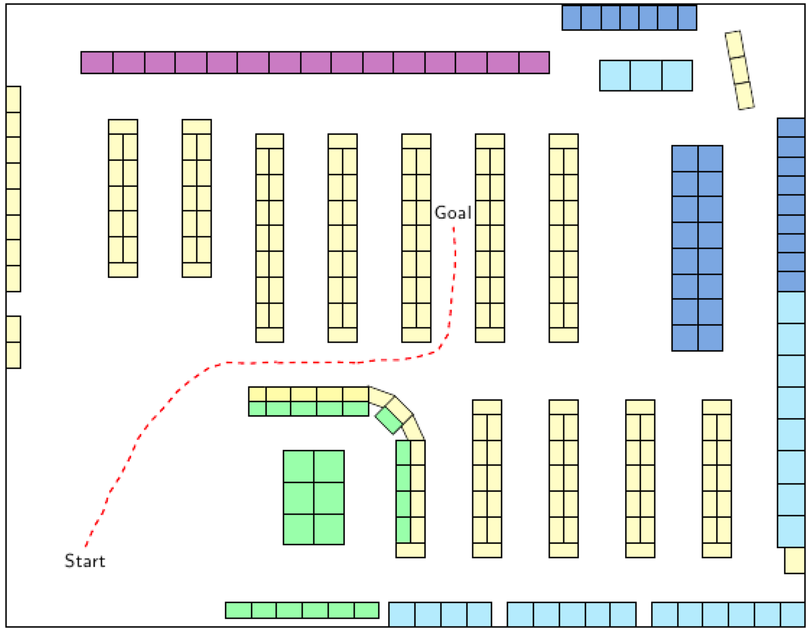
David Vernon
Carnegie Mellon University Africa

www.vernon.eu

Localization: The Position Estimation Problem

Two approaches

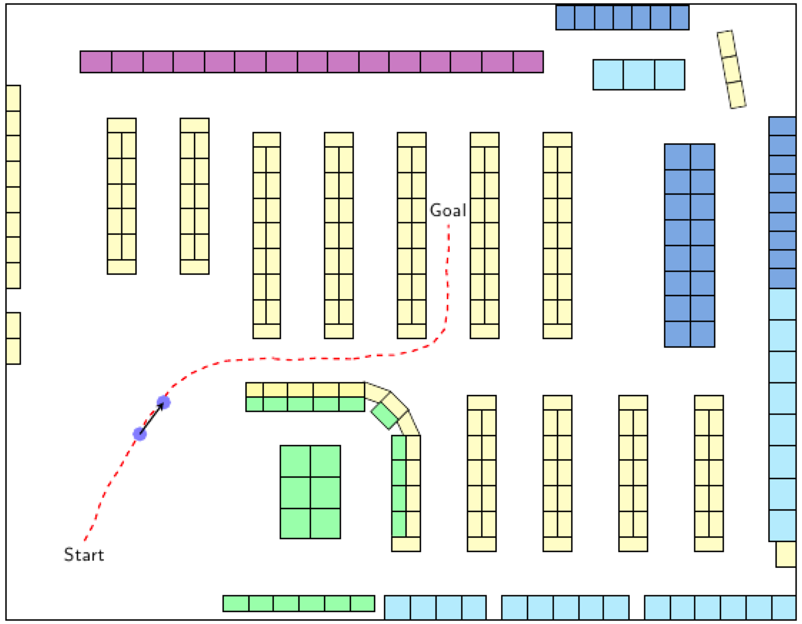
1. Absolute position estimation
2. Relative position estimation



Relative Position Estimation

Detect the change in the position and orientation of the robot: $(\Delta x, \Delta y, \Delta \theta)$

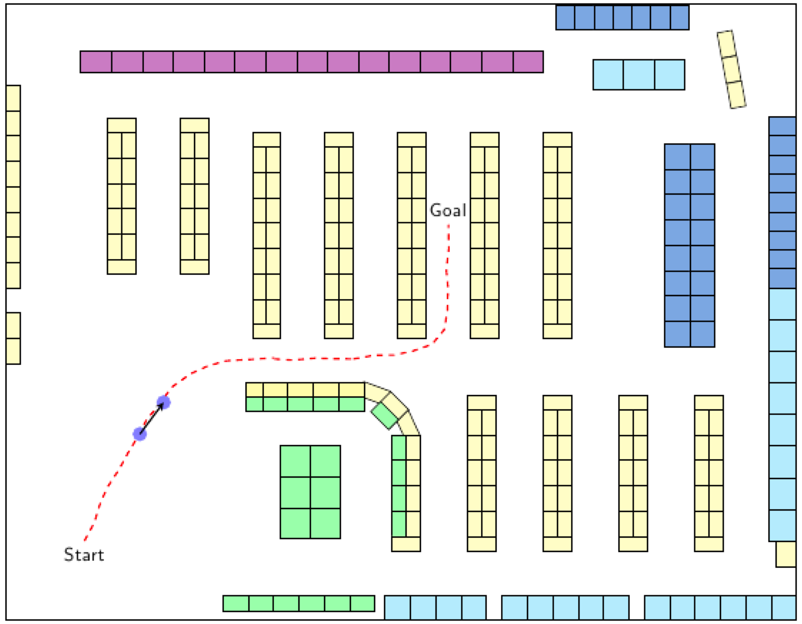
Combine the previous estimate and the change to determine the new estimate of the robot position



Relative Position Estimation

Options for detecting change in relative position:

- Inertial sensors
- Odometry



Inertial Position Estimation

Options for detecting change in relative position:

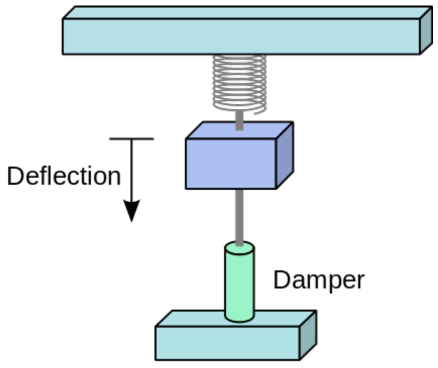
- Inertial sensors
  - Accelerometers sense change in position
  - Gyroscopes sense change in orientation

Inertial Position Estimation

Option for detecting change in relative position:

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



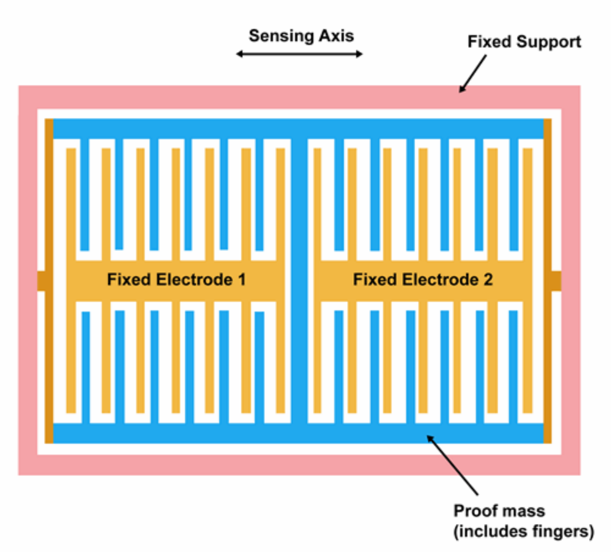
Source: https://en.wikipedia.org/wiki/Inertial_navigation_system

Inertial Position Estimation

Option for detecting change in relative position:

Accelerometer

- Miniature microelectromechanical systems (MEMS) accelerometer
- When the sensor is subjected to a linear acceleration along its sensing axis



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

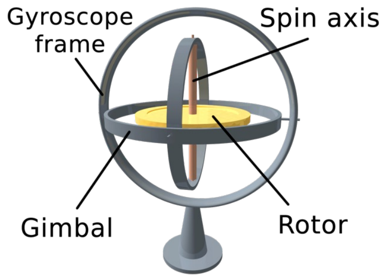
  - The proof mass and its fingers become displaced with respect to the fixed electrode fingers
  - The differential capacitance between the moving and fixed silicon fingers is measured
  - This is proportional to the acceleration

Inertial Position Estimation

Option for detecting change in relative orientation:

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

Inertial Position Estimation

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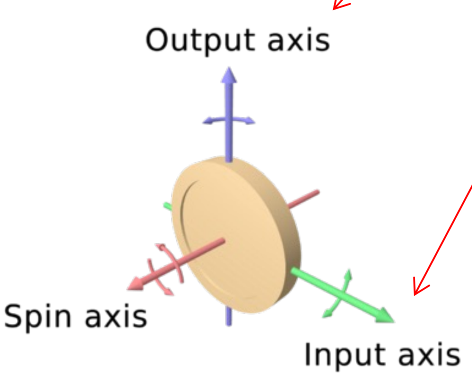
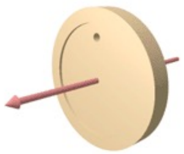
Imposing a rotation about this axis

causes a rotation about this axis





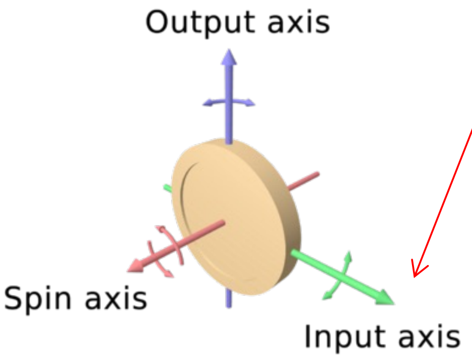
Source: https://en.wikipedia.org/wiki/Gyroscope

See https://www.youtube.com/watch?v=mRZGdvJQnPU for an explanation of gyroscopic precession, i.e., the relationship between angular momentum and applied torque

Inertial Position Estimation

Sensing the rotation
on this axis

allows you to measure the
change in orientation
in this axis



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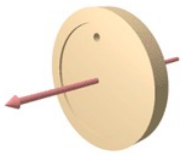


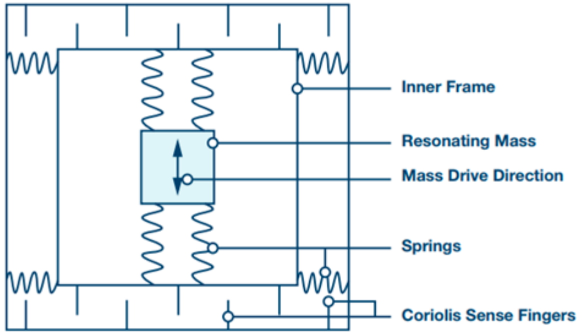
Source: https://en.wikipedia.org/wiki/Gyroscope

Inertial Position Estimation

Option for detecting change in relative orientation:

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

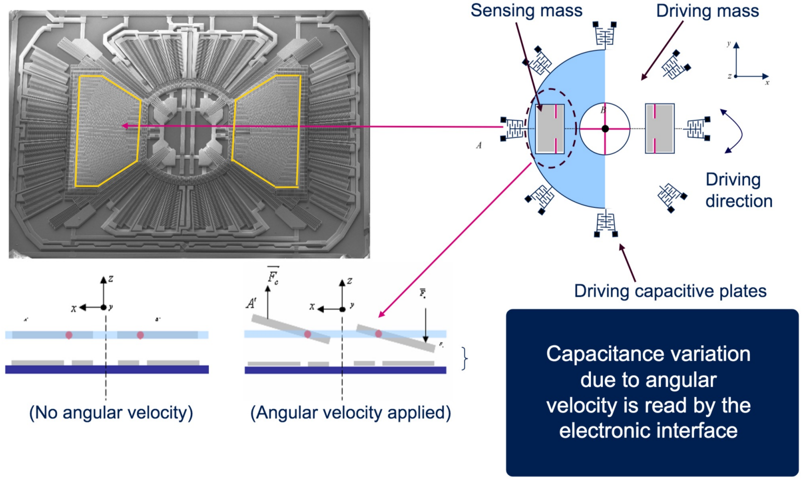
Inertial Position Estimation

Option for detecting change in relative orientation:

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

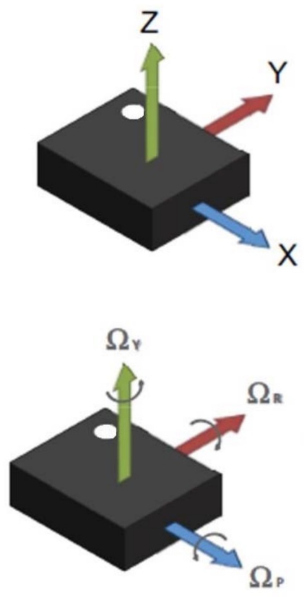
Inertial Position Estimation

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

Inertial Position Estimation

Options for detecting change in relative position:

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

Inertial Position Estimation

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

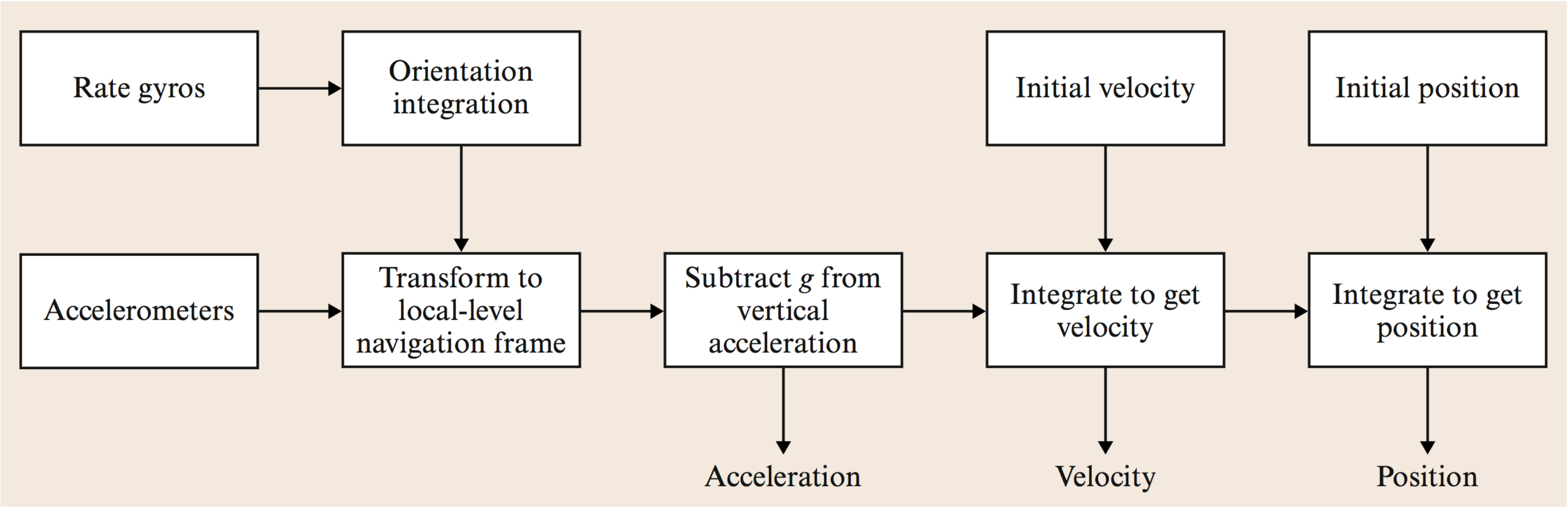
Initial velocity of the object

Initial position of the object

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

Inertial Position Estimation

Block diagram for estimating position with an IMU



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

Inertial Position Estimation

- Precise estimate if
  - initial estimate of v_0 and s_0 are precise
  - measurement of $a(t)$ is precise

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

- However, sensors are not perfect, and 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

Reading

M. Mataric, The Robotics Primer, MIT Press, 2007. Chapter 7.