Robotics: Principles and Practice

Module 3: Mobile Robots

Lecture 3: Relative position estimation using inertial sensors

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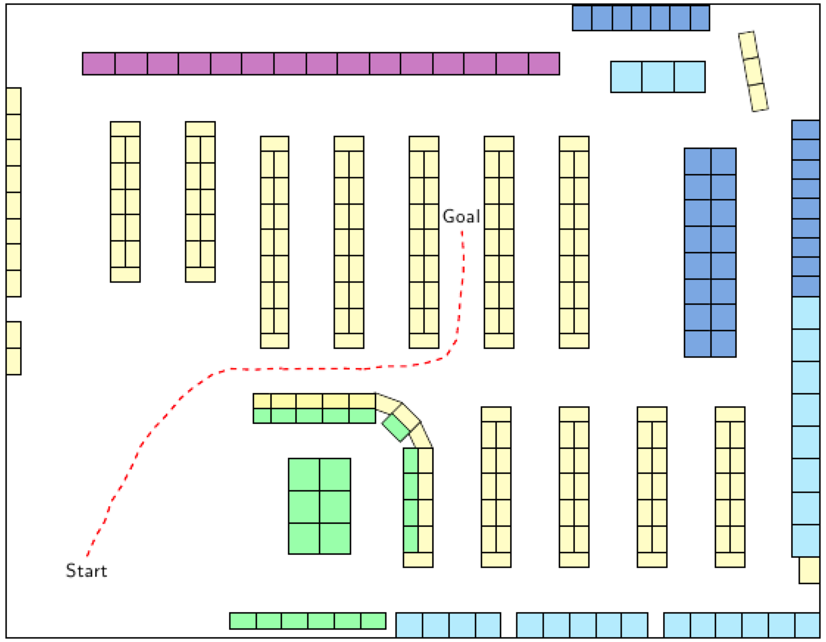
Localization: The Position Estimation Problem

Two approaches

1. Absolute position estimation

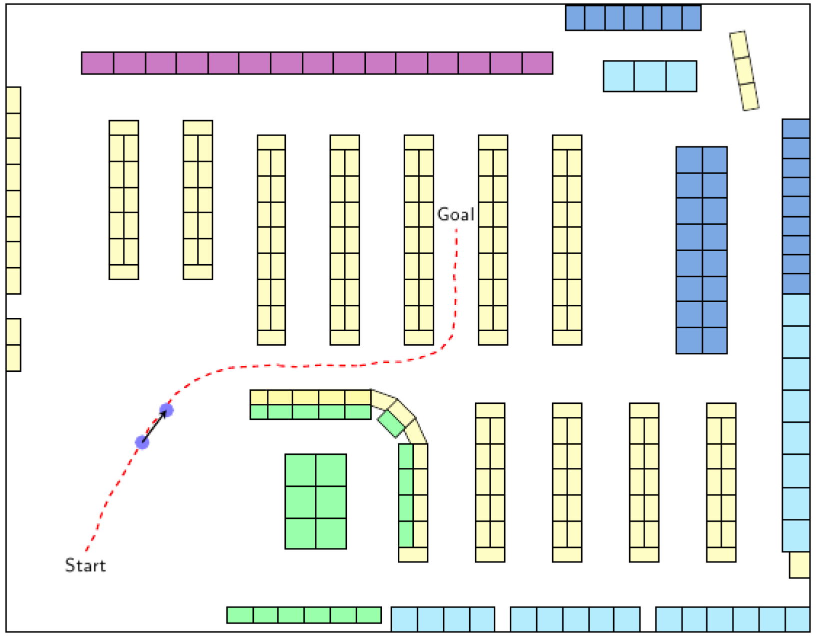
2. Relative position estimation



Relative Position Estimation

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

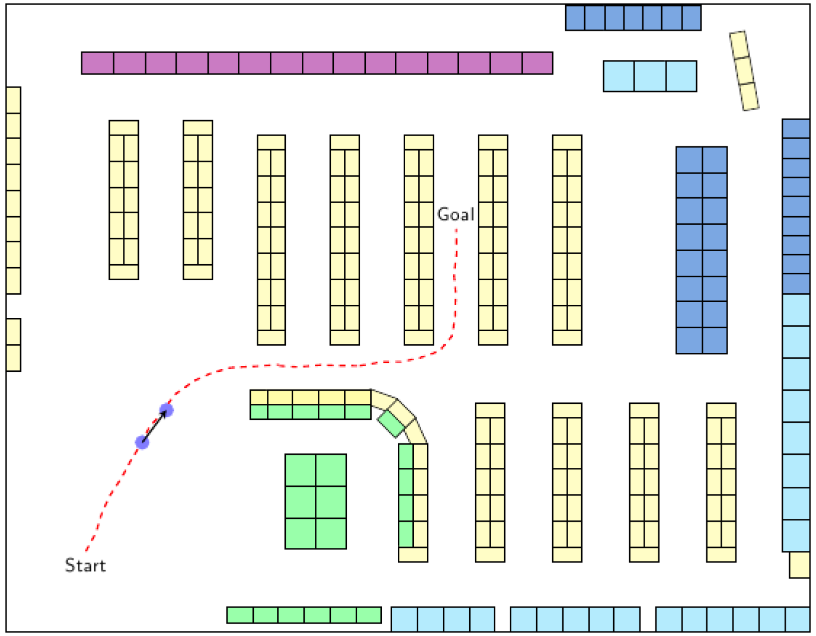
Combine the previous estimate and the change to determine the new estimate of the robot position



Relative Position Estimation

Options for detecting change in relative position:

- Inertial sensors
- Odometry



Inertial Position Estimation

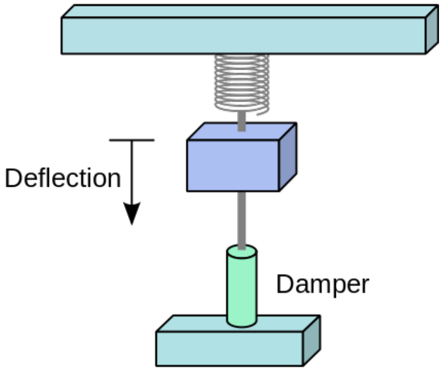
Options for detecting change in relative position:

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

Inertial Position Estimation

Option for detecting change in relative position:

Accelerometer

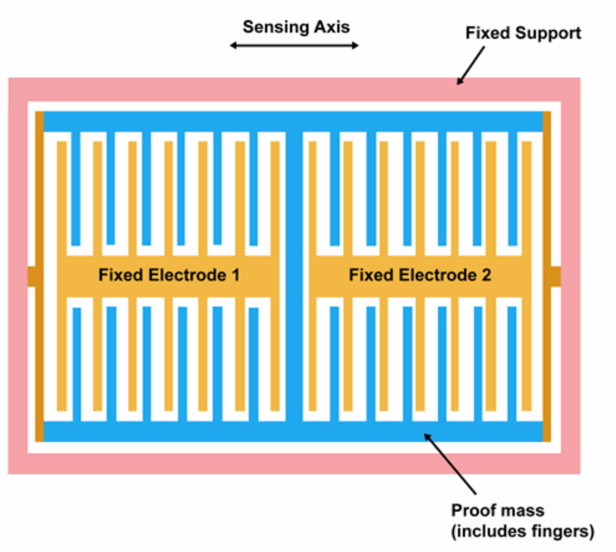


Source: https://en.wikipedia.org/wiki/Inertial_navigation_system

- 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

Inertial Position Estimation

Option for detecting change in relative position:



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

Accelerometer

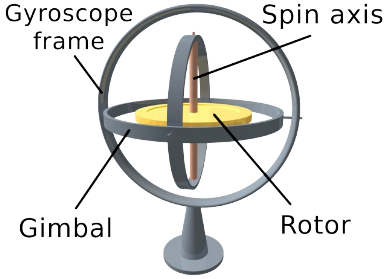
- Miniature microelectromechanical systems (MEMS) accelerometer
- When the sensor is subjected to a linear acceleration along its sensing axis
  - The proof mass and its fingers become displaced with respect to the fixed electrode fingers
  - The differential capacitance between the moving and fixed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

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

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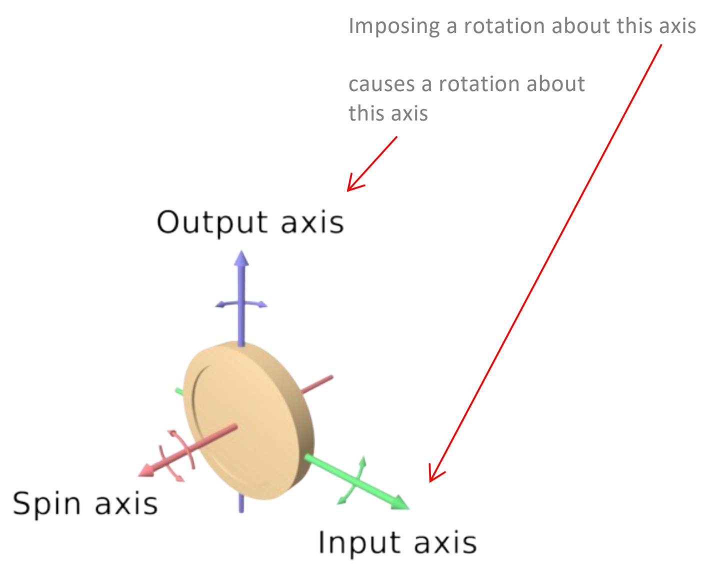

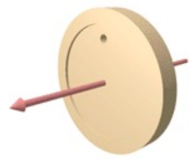

Source: https://en.wikipedia.org/wiki/Gyroscope

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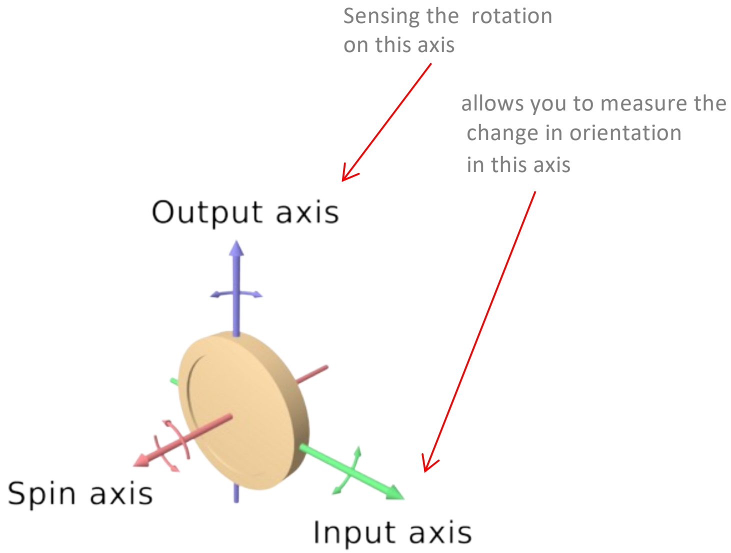
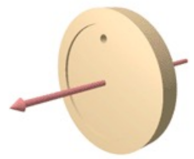




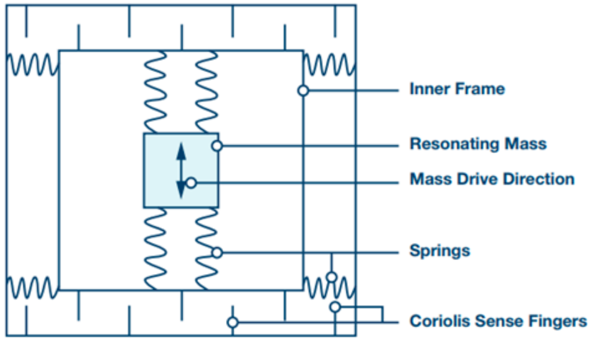
Source: https://en.wikipedia.org/wiki/Gyroscope

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

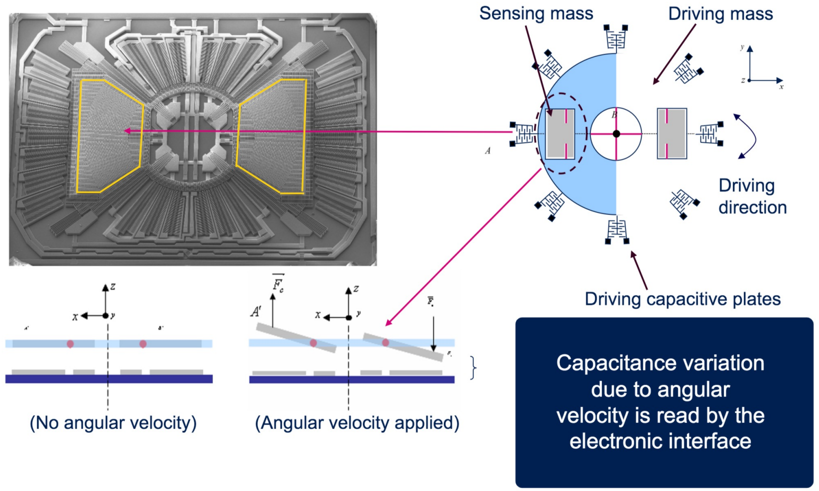
Inertial Position Estimation

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)

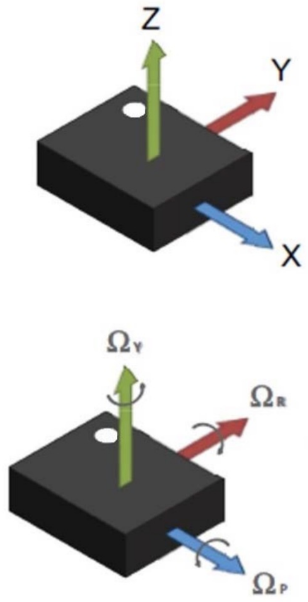


Source: https://www.st.com/en/mems-and-sensors/gyroscopes.html

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 change in 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

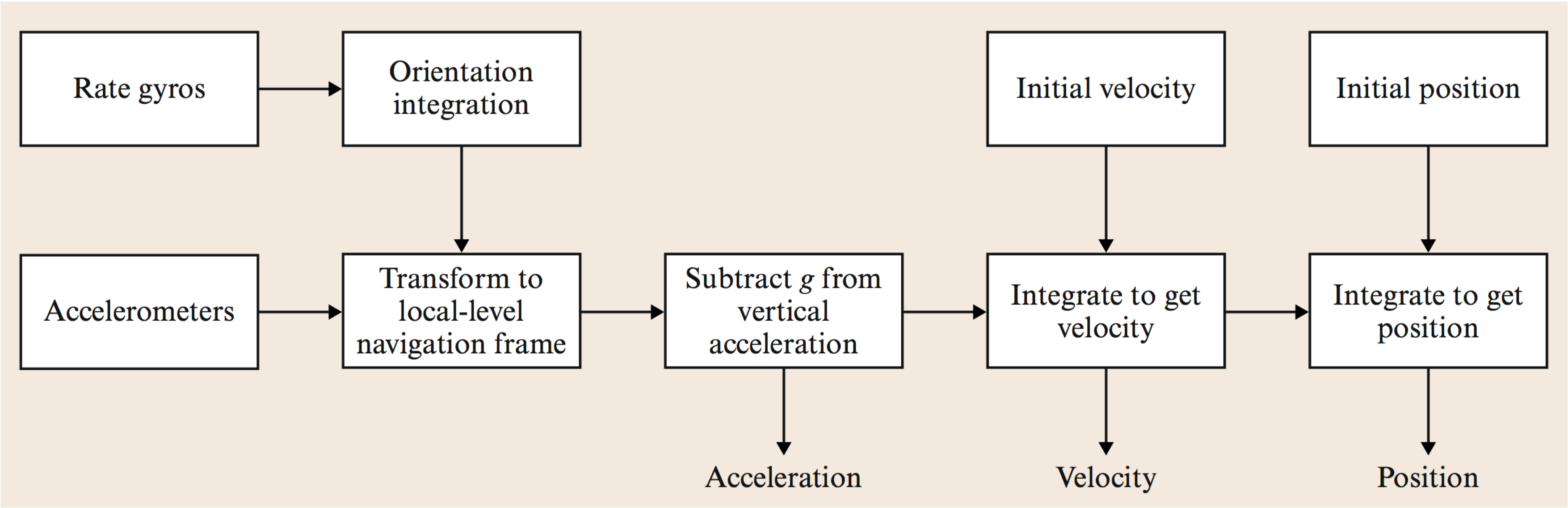
Initial velocity of the object

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
- 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

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

Reading

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