Inertial Navigation

Definition: Given the vehicle's initial position and velocity, estimate the vehicle's current position and velocity relative to the starting point, using only proprioceptors that measure rigid body mechanical properties (e.g., accelerometers and gyroscopes).

Inertial Measurement Unit (IMU): Contains a cluster of sensors attached to a common base.

- accelerometers (typically 3 or more along orthogonal axes) measure accelerations of the sensor's body-fixed reference frame,
- gyroscopes measure the rates of sensor rotation about three orthogonal axes.
- An optional *magnetometer* measure's the earth's magnetic field (i.e., a compass)

Basic Concept: Integrate accelerometer twice to obtain velocity and position. Integrate gyro readings to estimate orientation.
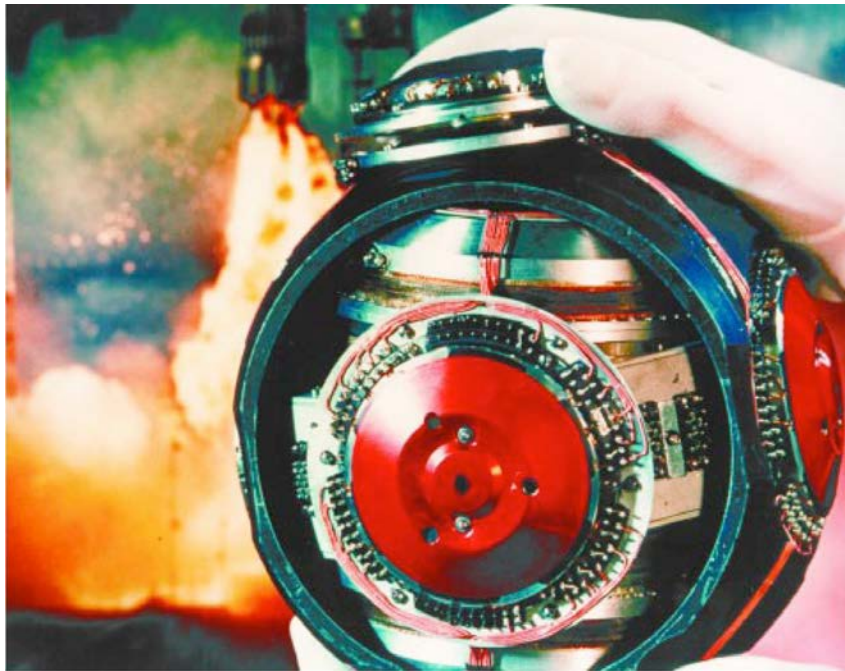
Basic types of IMUs

Gimbaled: The sensor suite is mounted on a platform in a gimbal.
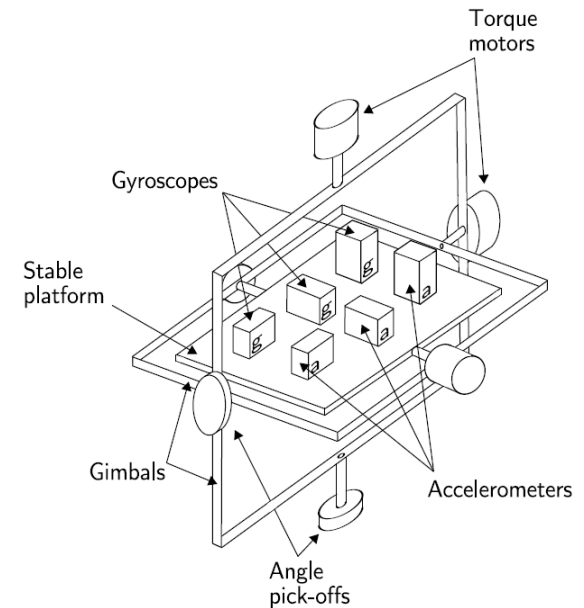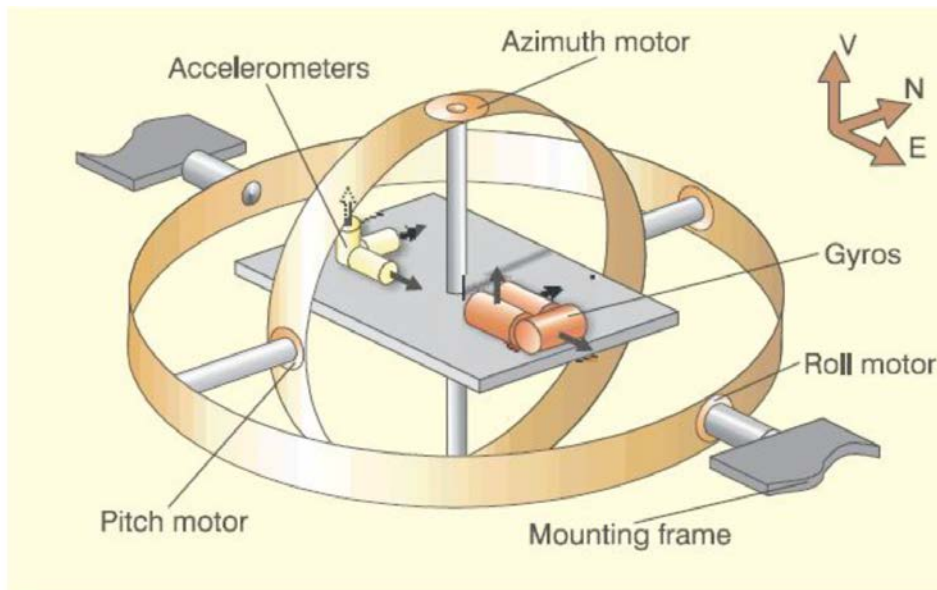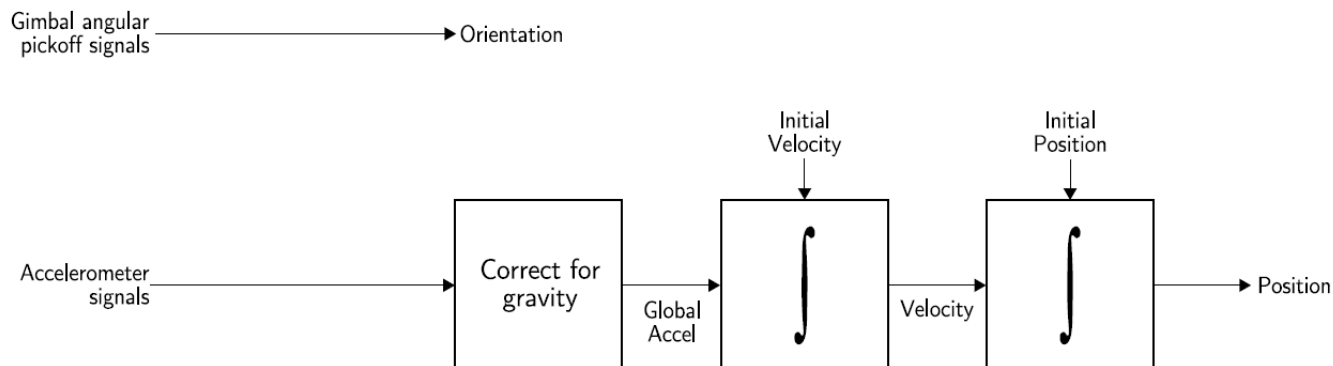
Basic types of IMUs

Gimbaled: The sensor suite is mounted on a platform in a gimbal.

Mechanical Gyro: A spinning wheel will resist any change to its angular momentum vector. Maintains constant orientation if in a frictionless gimbal

How does gimbaled INS Work

- The output of an "integrating gyro" is proportional to the angle through which they have been rotated

- Each gyro output is coupled to a servo-motor, which generates a torque as needed to maintain constant gymbal orientation in inertial space -> try to "null" the difference between the gyro rate and the gimbal axis rotation rate.

- The gyro motors can create "fictitious" inputs which can be used to counteract "*drift,*" a major cause of inertial nagivation errors.

Basic types of IMUs

Strapdown: Mount sensor suite rigidly to the moving object of interest.
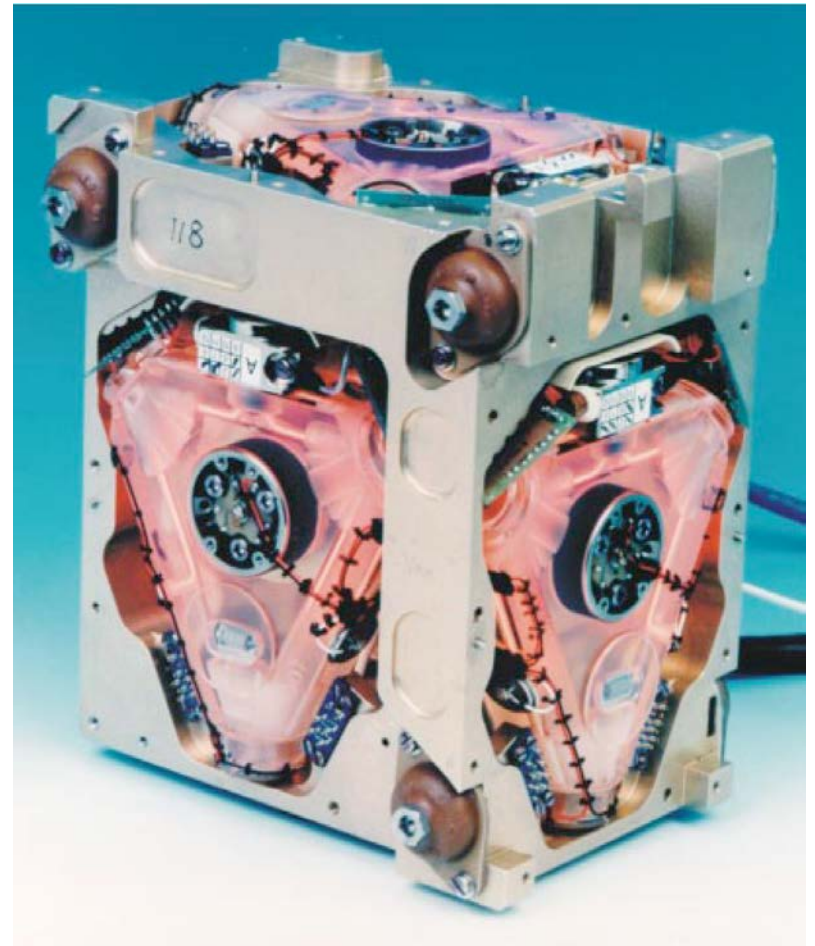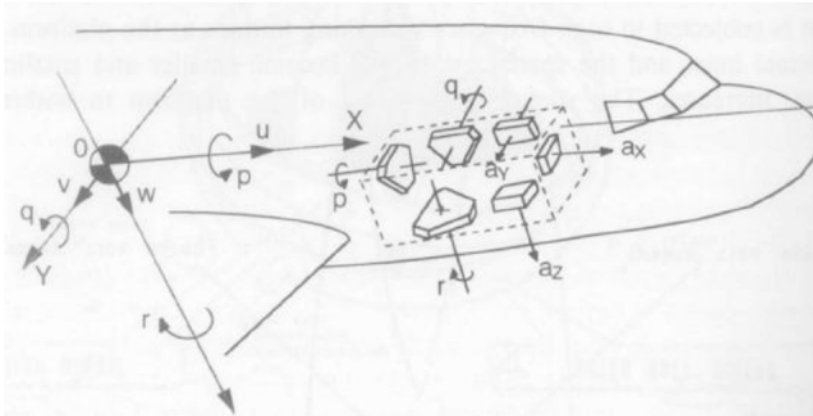
Strapdown Gyros (1)

The Sagnac-effect. The inertial characteristics of light can also be utilized, by letting two beams of light travel in a loop in opposite directions. If the loop rotates clockwise, the clockwise beam must travel a longer distance before finishing the loop. The opposite is true for the counter-clockwise beam. Combining the two rays in a detector, an interference pattern is formed, which will depend on the angular velocity.

The loop can be implemented with 3 or 4 mirrors (*Ring Laser Gyro*), or with optical fibers (*Fiber Optic Gyro*).
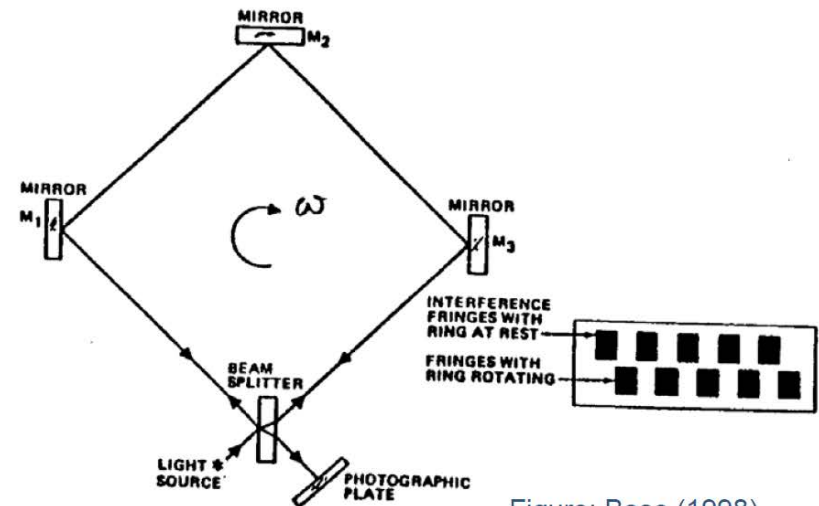
Figure: Bose (1998)

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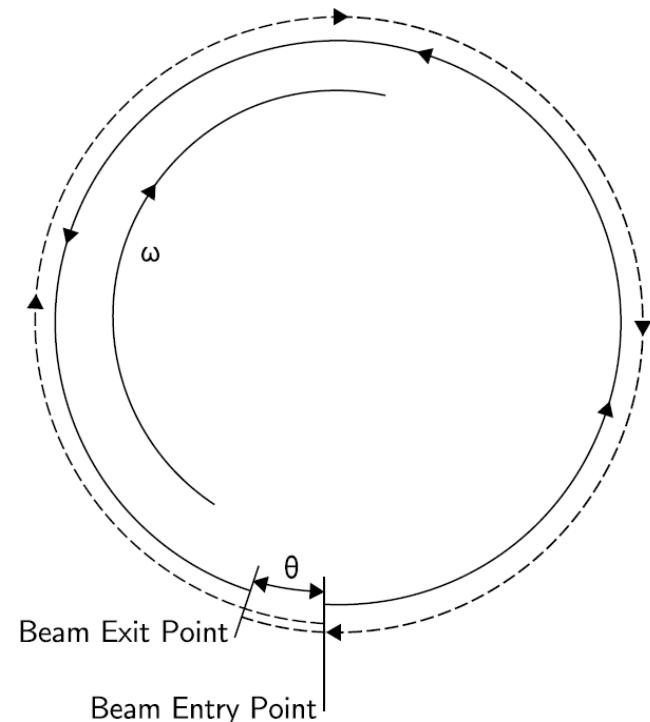
ω

θ

Beam Exit Point

Beam Entry Point

Strapdown Gyros (2)

Coriolis Effect: When a mass vibrating in a radial direction is rotated, the Coriolis effect will cause new vibrations perpendicular to the original vibration axis.

- Cheaper MEMS gyros use this principle ("tuning fork" or "wineglass")
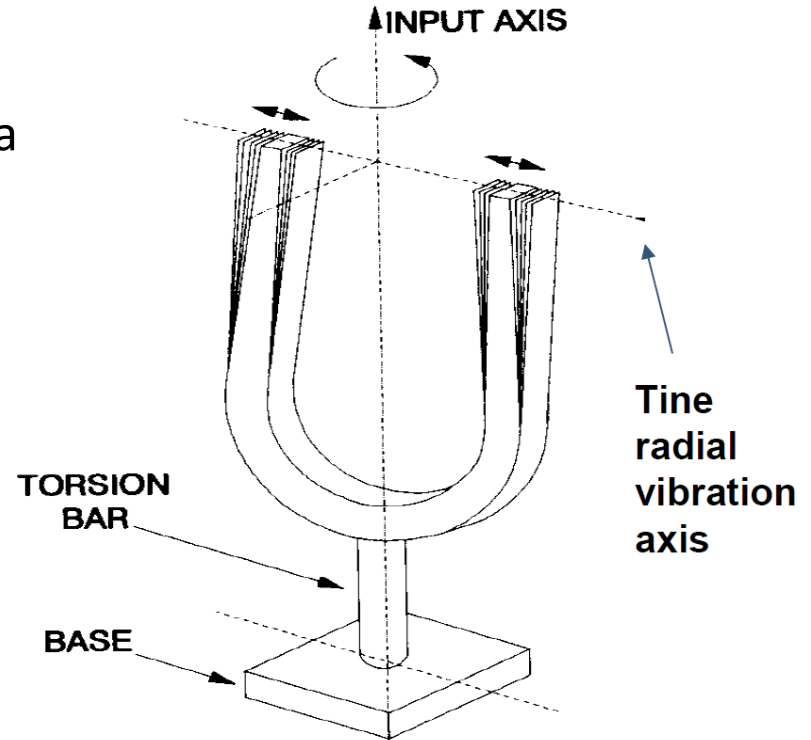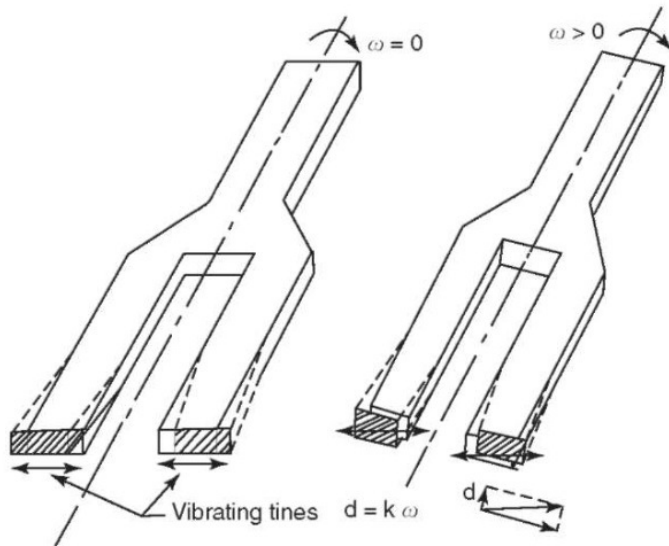- Less accurate than ring or fiber gyro

INPUT AXIS

TORSION BAR

BASE

Tine radial vibration axis

Figure: Titterton & Weston (1997)

$\omega = 0$ $\omega > 0$

Vibrating tines $d = k\omega$

lateral deflection sensor

vertical deflection sensor

light boron doping (piezoresistive)

heavy boron doping (highly conductive)
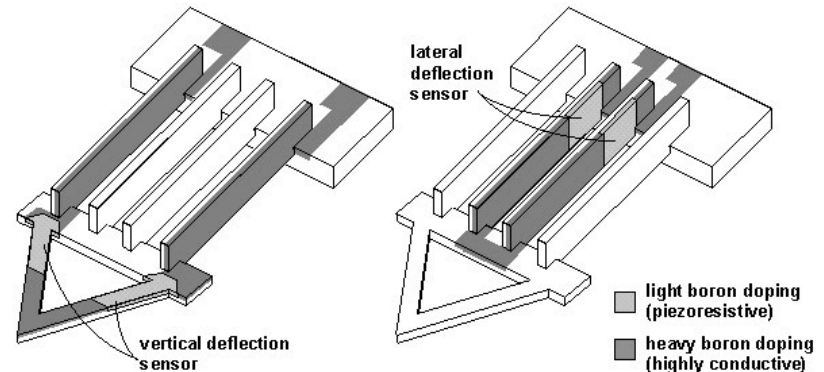
Accelerometers

Vibration: deflection of a mass on a spring yields simple acceleration signal
- Greater accuracy, dynamic range, and linearity can be realized by keeping mass close to nominal position—control forces are proportional to acceleration.
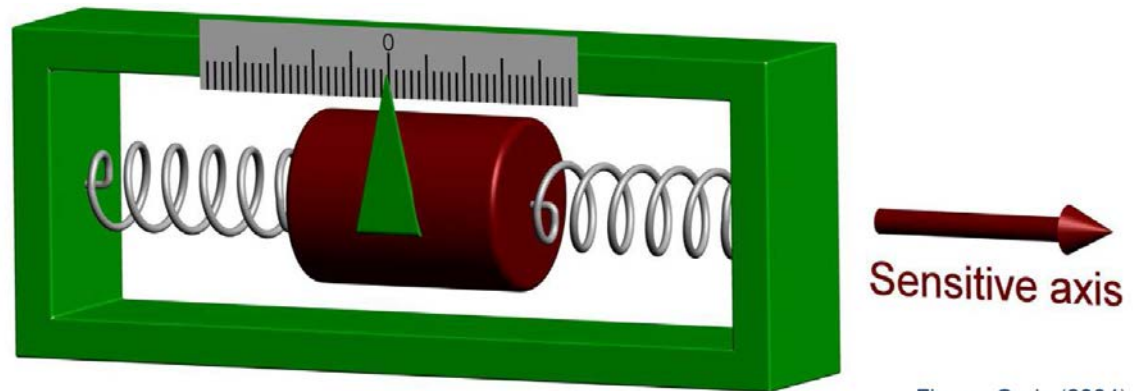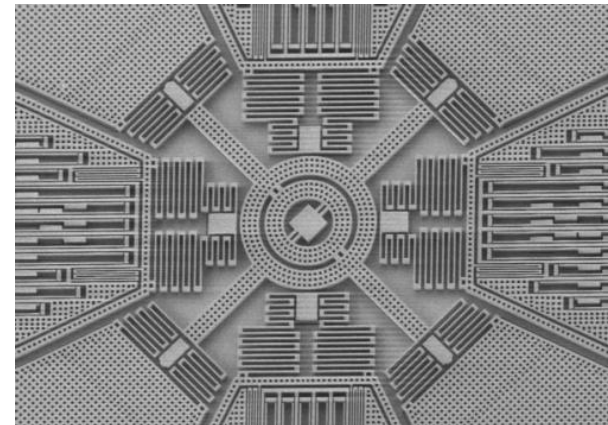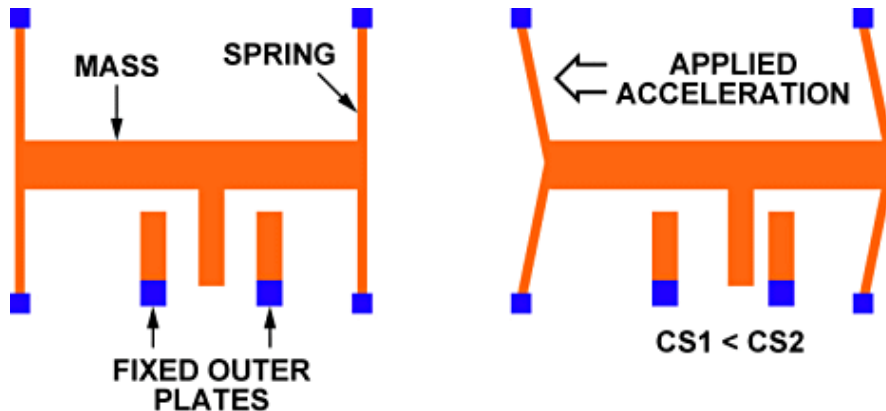

Sensitive axis

Figure: Gade (2004)

MASS   SPRING

FIXED OUTER PLATES

APPLIED ACCELERATION

CS1 < CS2

Terrestrial Navigation

Corrections need to be added to inertial navigation when the vehicle is operating or navigation on earth, since *earth is not an inertial system*

Gyros:
- The earth rotates: $\omega_{EB} = \omega_{IB} - \omega_{IE}$ (ω_{IE} = earth's rotation in space)

Accelerometers
- also measure *gravitational acceleration*
  - Let a_{IB} denote the acceleration of the body measured relative to an inertial frame.
  - Let g_B denote the gravitational acceleration
  - The *specific force, f_{IB}*, measures the acceleration in an inertial frame: $f_{IB} = a_{IB} - g$
- Also measure centrifugal and Coriolis forces due to movement in earth's rotating frame.
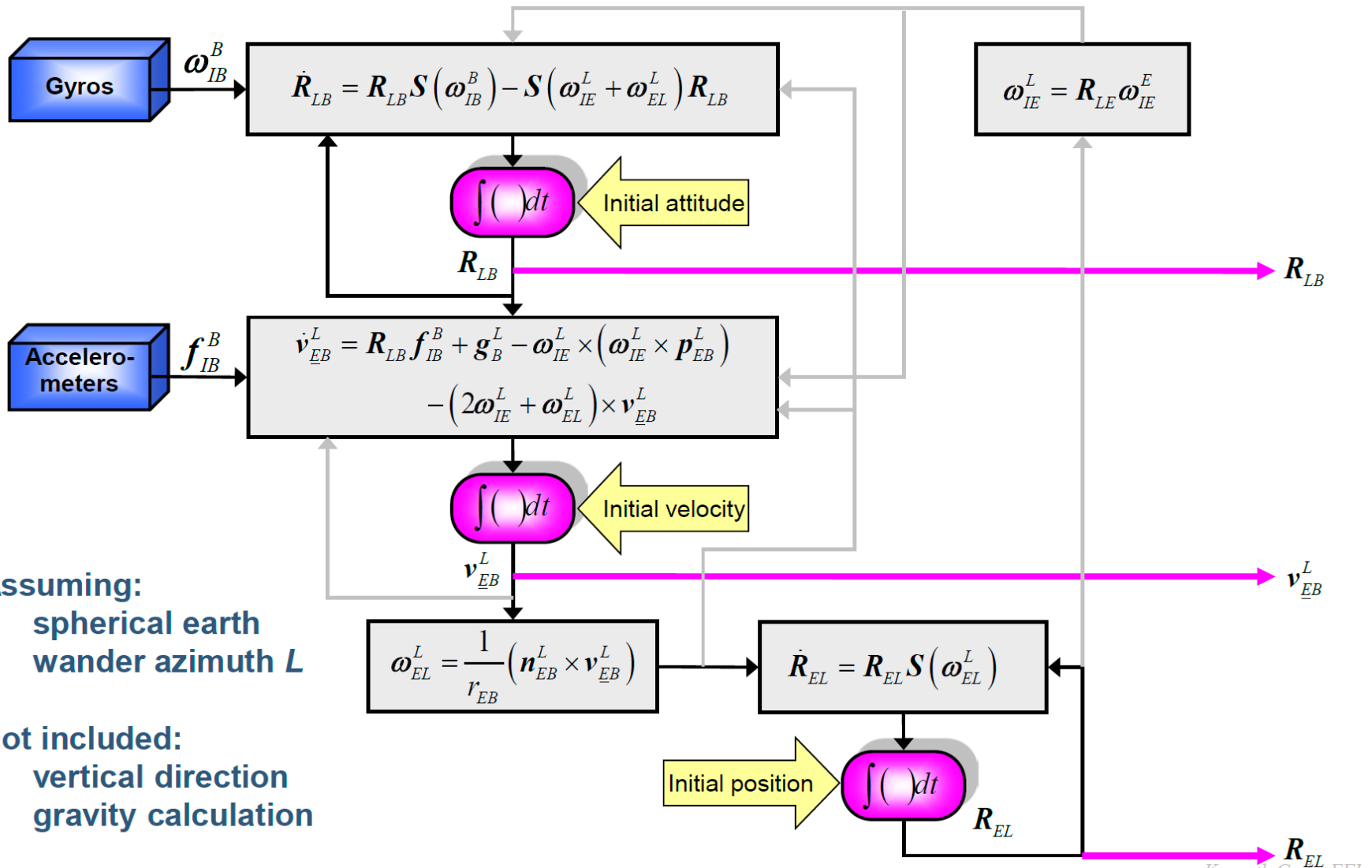
Terrestrial Navigation

Important coordinate frames

Frame symbol	Description
I	Inertial
E	Earth-fixed
B	Body-fixed
N	North-East-Down (local level)
L	Local level, wander azimuth (as *N*, but not north-aligned => nonsingular)

North Pole

wander azimuth

N

L

x

y

z

latitude

longitude

Equator

Prime meridian

B

(Figure assumes spherical earth)

Figure: Gade (2008)

R_{EL} ⇔ longitude, latitude, wander azimuth

R_{NB}, R_{LB} ⇔ roll, pitch, yaw