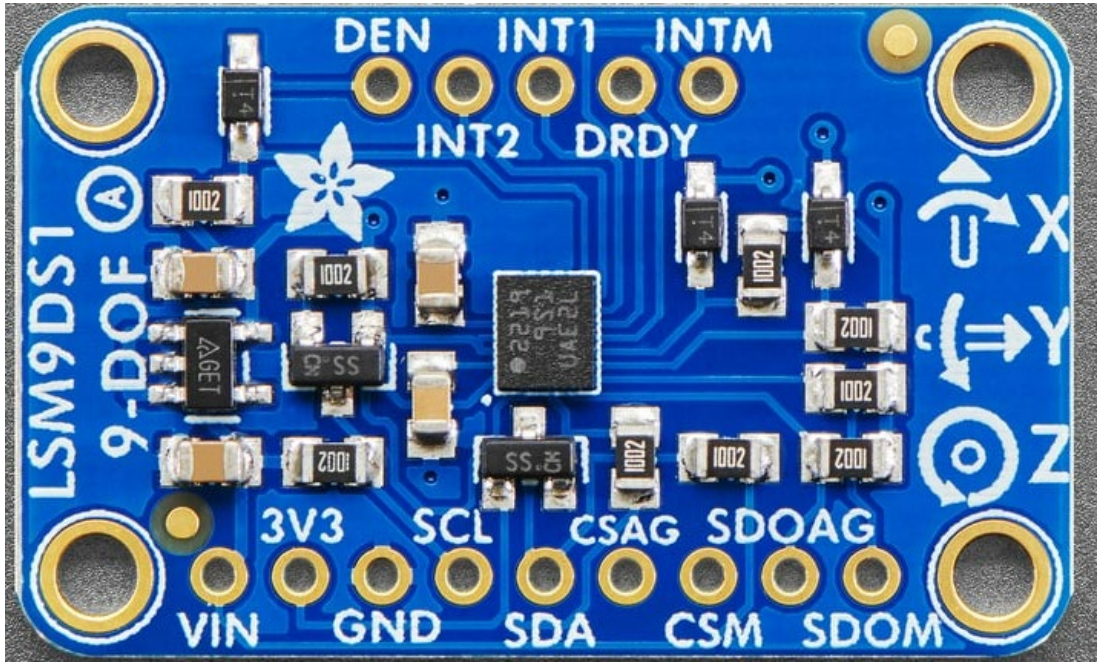
P524: Survey of Instrumentation and Laboratory Techniques Week 8

Sensors: motion, proximity, temperature, voltage

10/15/2026

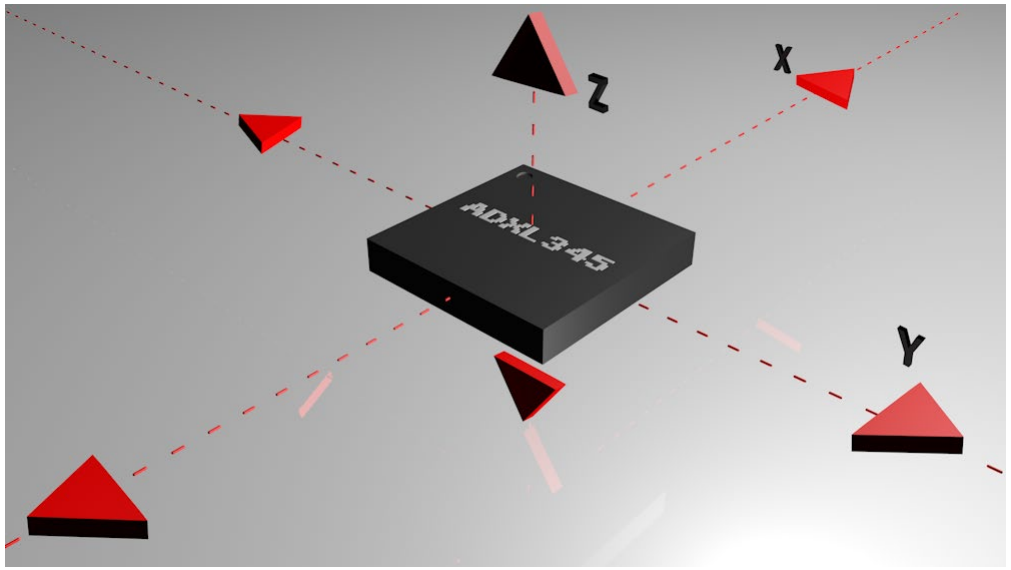
Sensors I: motion



LSM9DS1 “9 axis” motion sensor:

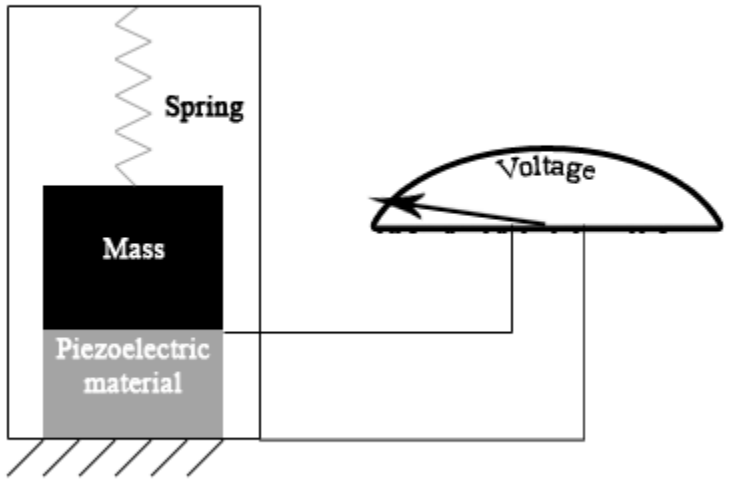
- Inertial Measurement Units (IMU)
- Sensor chip made by STMicroelectronics
- 9-axis iNEMO IMU:
  - 3D magnetometer,
  - 3D accelerometer,
  - 3D gyroscope
  - with I2C and SPI

Accelerometer



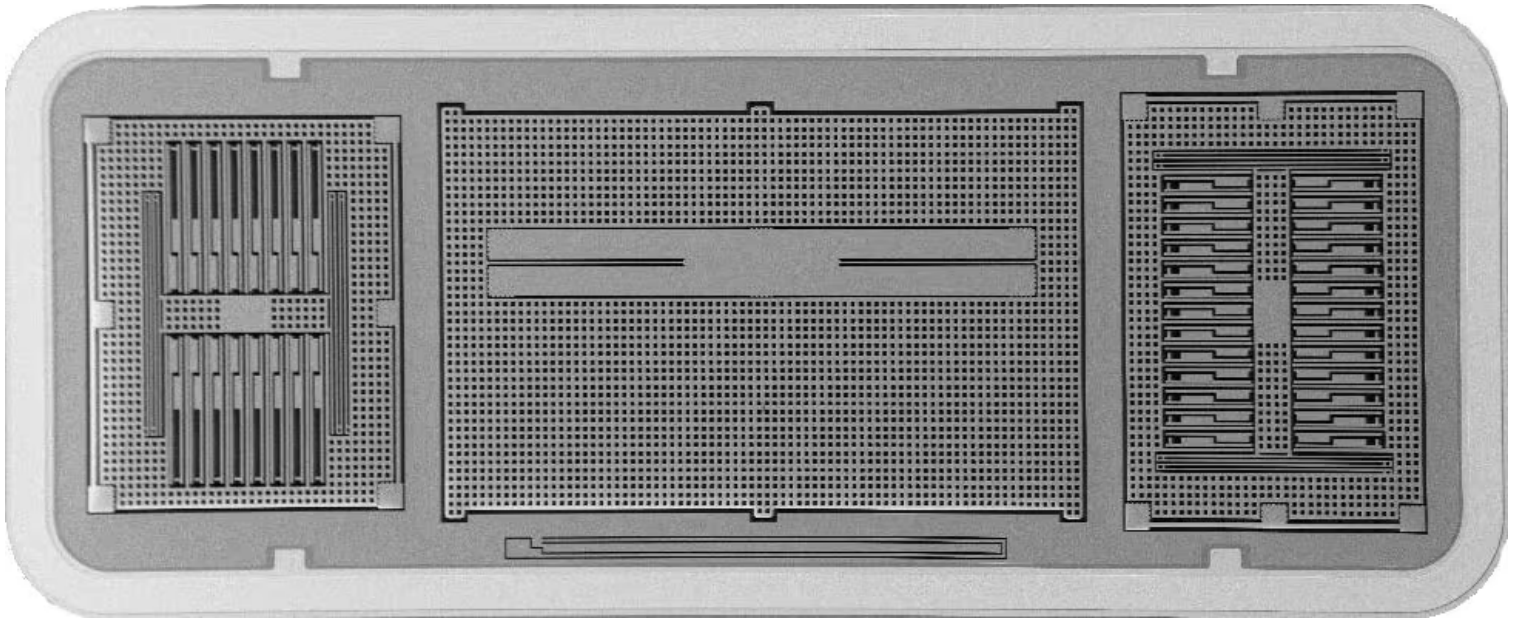
- Accelerometers are devices that measure acceleration, which is the rate of change of the velocity of an object. Typical units are meters per second squared (m/s^2) or in gs (g). A single g on planet Earth is equivalent to 9.8 m/s^2, but varies slightly with elevation (and will be a different value on different planets with different masses). Accelerometers are useful for sensing vibrations in systems or for orientation applications.

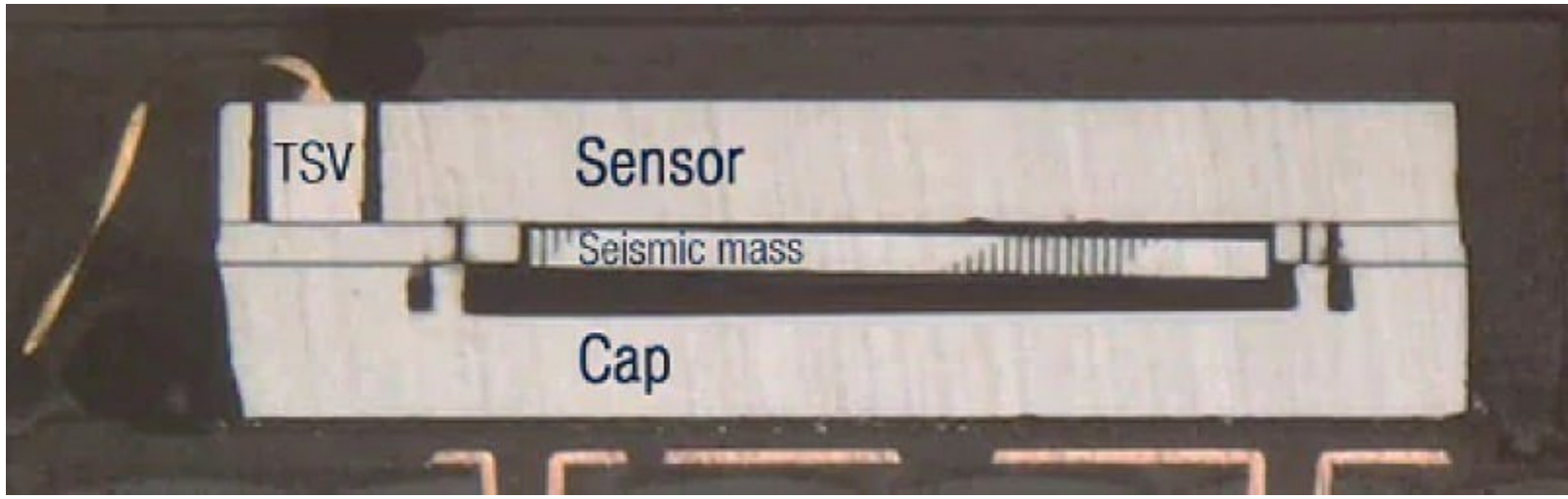
- Accelerometers contain capacitive plates, some fixed, others attached to minuscule springs that move internally as acceleration forces act upon the sensor. As these plates move in relation to each other, the capacitance between them changes. From these changes in capacitance, the acceleration can be determined.
- Other accelerometers use piezoelectric materials. These tiny crystal structures output electrical charge when placed under mechanical stress.
- MEMS (Micro-Electro-Mechanical systems)



MEMS sensors

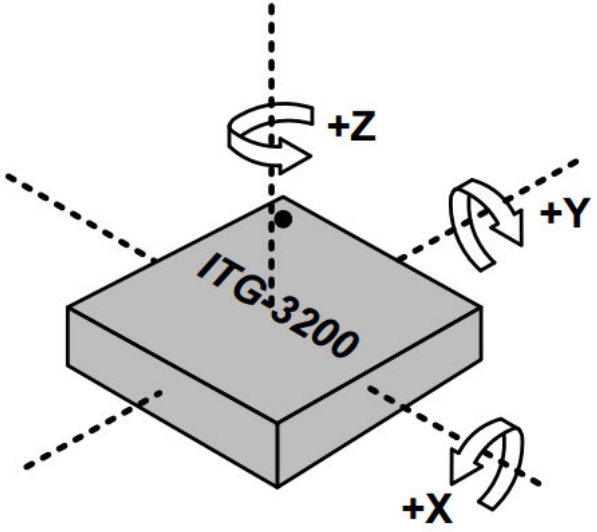
- MEMS (Micro-Electro-Mechanical systems) sensors leverage silicon's unique mechanical properties to integrate mechanical structures able to sense acceleration, rotation, angular rate, vibration, displacement, heading, and other

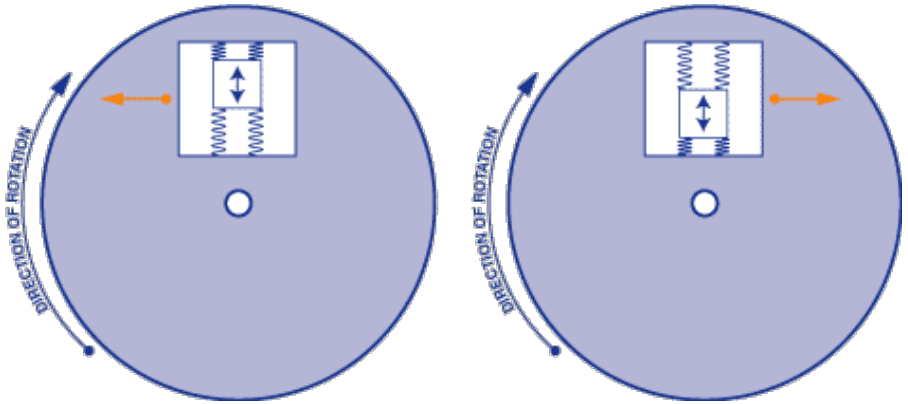




Gyroscope

- Gyroscopes, or gyros, are devices that measure or maintain rotational motion. MEMS (microelectromechanical system) gyros are small, inexpensive sensors that measure angular velocity. The units typically degrees per second (°/s, “dps”) or revolutions per second (RPS).
- A triple axis MEMS gyroscope, similar to the one pictured on the right (ITG-3200), can measure rotation around three axes: x, y, and z. Some gyros come in single and dual axis varieties, but the triple axis gyro in a single chip is becoming smaller, less expensive, and more popular.
- Gyros are often used on objects that are not spinning very fast at all. Aircrafts (hopefully) do not spin. Instead they rotate a few degrees on each axis. By detecting these small changes gyros help stabilize the flight of the aircraft. Also, note that the acceleration or linear velocity of the aircraft does not affect the measurement of the gyro. **Gyros only measure angular velocity**.
- How does the MEMS gyro detect angular velocity? The gyroscope sensor within the MEMS is tiny (between 1 to 100 micrometers, the size of a human hair). When the gyro is rotated, a small resonating mass is shifted as the angular velocity changes. This movement is converted into very low-current electrical signals that can be amplified and read by a host microcontroller.





Magnetometers

Hall effect magnetometer

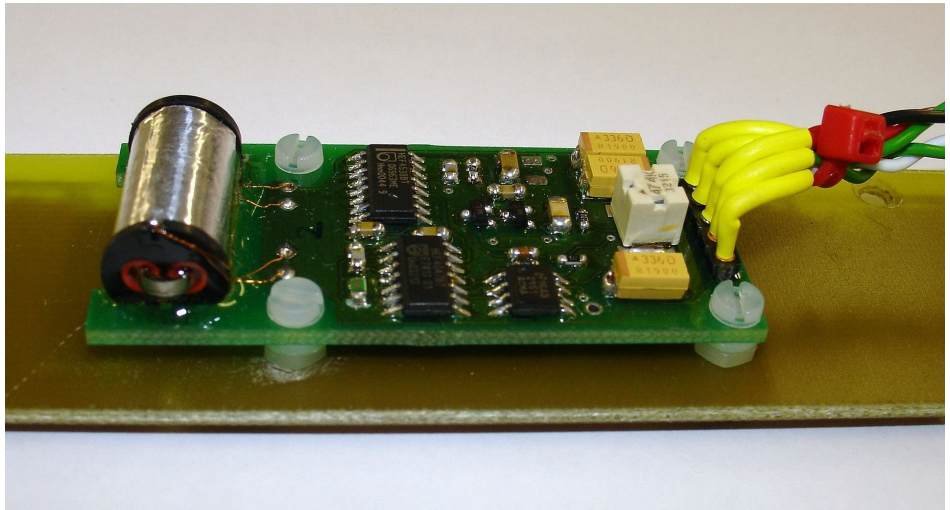
- The most common magnetic sensing devices are solid-state Hall effect sensors. These sensors produce a voltage proportional to the applied magnetic field and also sense polarity. They are used in applications where the magnetic field strength is relatively large, such as in anti-lock braking systems in cars, which sense wheel rotation speed via slots in the wheel disks.

Magnetoresistive devices

- These are made of thin strips of Permalloy, a high magnetic permeability, nickel-iron alloy, whose electrical resistance varies with a change in magnetic field. They have a well-defined axis of sensitivity, can be produced in 3-D versions and can be mass-produced as an integrated circuit. They have a response time of less than 1 microsecond and can be sampled in moving vehicles up to 1,000 times/second. They can be used in compasses that read within 1°, for which the underlying sensor must reliably resolve 0.1°.

Fluxgate magnetometer

A fluxgate magnetometer consists of a small magnetically susceptible core wrapped by two coils of wire. An alternating electric current is passed through one coil, driving the core through an alternating cycle of magnetic saturation; i.e., magnetised, unmagnetised, inversely magnetised, unmagnetised, magnetised, and so forth. This constantly changing field induces a voltage in the second coil which is measured by a detector.



Gyroscope Datasheets

- https://learn.adafruit.com/comparing-gyroscope-datasheets

- L3GD20 3 Axis MEMS Gyroscope - ST
- FXAS21002C 3 Axis MEMS Gyroscope - NXP
- LSM9DS0 9 Axis* MEMS Sensor (Accel + Mag + Gyro) - ST
- LSM9DS1 9 Axis* MEMES Sensor (Acce + Mag + Gyro) - ST
- MPU-9250 9 Axis* MEMS Sensor (Accel + Mag + Gyro) - Invensense
- BMI055 6 Axis MEMS Sensor (Accel + Gyro) - Bosch (Used in the BNO055)

	Dynamic Range (dps)	ADC
L3GD20	250/500/2000	16 bits
FXAS21002C	250/500/1000/2000	16 bits
LSM9DS0	245/500/2000	16 bits
LSM9DS1	245/500/2000	16 bits
MPU-6250	250/500/1000/2000	16 bits
BMI055	125/250/500/1000/2000	16 bits

LSM9DS1

G_FS	Angular rate measurement range			±245		dps
				±500		
				±2000		
LA_So	Linear acceleration sensitivity	Linear acceleration FS = ±2 *g*		0.061		mg/LSB
		Linear acceleration FS = ±4 *g*		0.122		
		Linear acceleration FS = ±8 *g*		0.244		
		Linear acceleration FS = ±16 *g*		0.732		
M_GN	Magnetic sensitivity	Magnetic FS = ±4 gauss		0.14		mgauss/ LSB
		Magnetic FS = ±8 gauss		0.29		
		Magnetic FS = ±12 gauss		0.43		
		Magnetic FS = ±16 gauss		0.58		
G_So	Angular rate sensitivity	Angular rate FS = ±245 dps		8.75		mdps/ LSB
		Angular rate FS = ±500 dps		17.50		
		Angular rate FS = ±2000 dps		70		
LA_TyOff	Linear acceleration typical zero-g level offset accuracy(2)	FS = ±8 *g*		±90		mg
M_TyOff	Zero-gauss level (3)	FS = ±4 gauss		±1		gauss
G_TyOff	Angular rate typical zero-rate level (4)	FS = ±2000 dps		±30		dps
M_DF	Magnetic disturbance field	Zero-gauss offset starts to degrade			50	gauss
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed
2. Typical zero-*g* level offset value after soldering
3. Typical zero-gauss level value after test and trimming
4. Typical zero rate level offset value after MSL3 preconditioning

Homework (due 10/22)

Inertial navigation

- By integrating the acceleration twice, it is (in principle) possible to determine the change in position of an object initially at rest. Code up, to run on your Arduino, an algorithm that will sample the LSM9DS1 acceleration at a high rate, determine the time interval between measurements, and figure out how much it has moved during the course of a few seconds of being pushed along a *single horizontal axis*.