UAV Workshop

Quadrotor Sensors

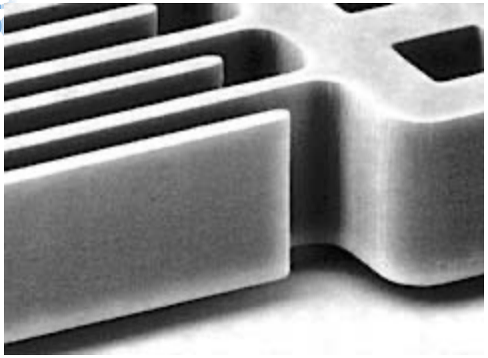
Prof. Venki Muthukumar, Ph.D.

Sensors

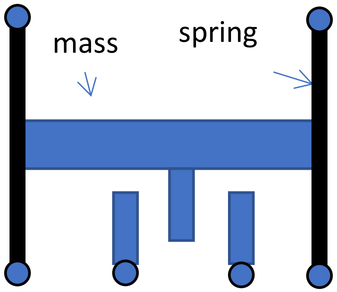
- IMUs (inertial measurement units)
  - Accelerometers
  - Gyroscopes
- Range sensors (sonar)
- GPS
- Cameras

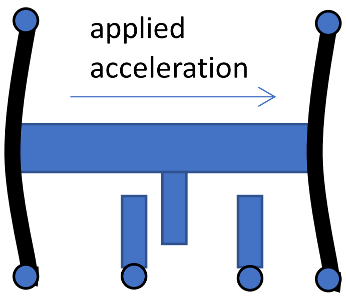
MEMS Accelerometers

- Micro Electro-Mechanical Systems (MEMS)
- Spring-like structure with a proof mass
- Damping results from residual gas
- Implementations: capacitive, piezoelectric, …



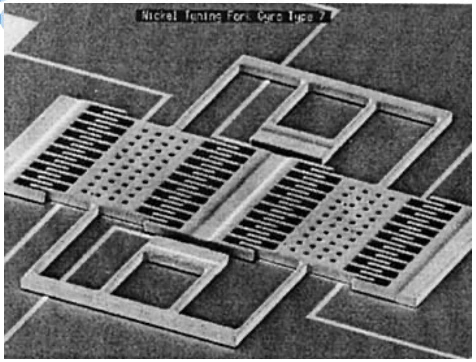
Bernstein, J., An Overview of MEMS Inertial Sensing Technology, Sensors, Feb. 2003.





MEMS Gyroscopes

- Vibrating structure gyroscope (MEMS)
  - Based on Coriolis effect
  - “Vibration keeps its direction under rotation”
  - Implementations: Tuning fork, vibrating wheels, …



Bernstein, J., An Overview of MEMS Inertial Sensing Technology, Sensors, Feb. 2003.

GPS

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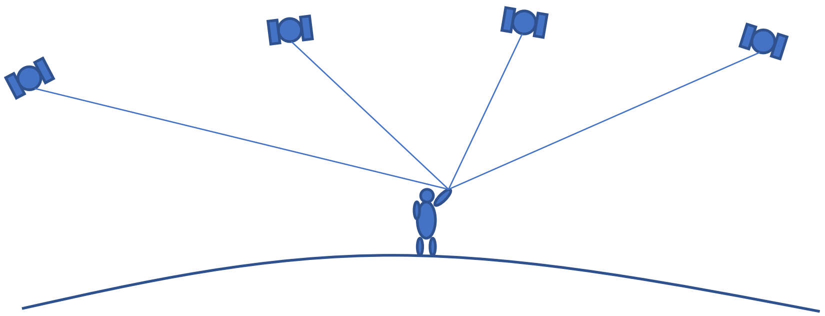
- Every satellite transmits its position and time
- Receiver measures time difference of satellite signals
- Calculate position by intersecting distances (pseudoranges)



IMU

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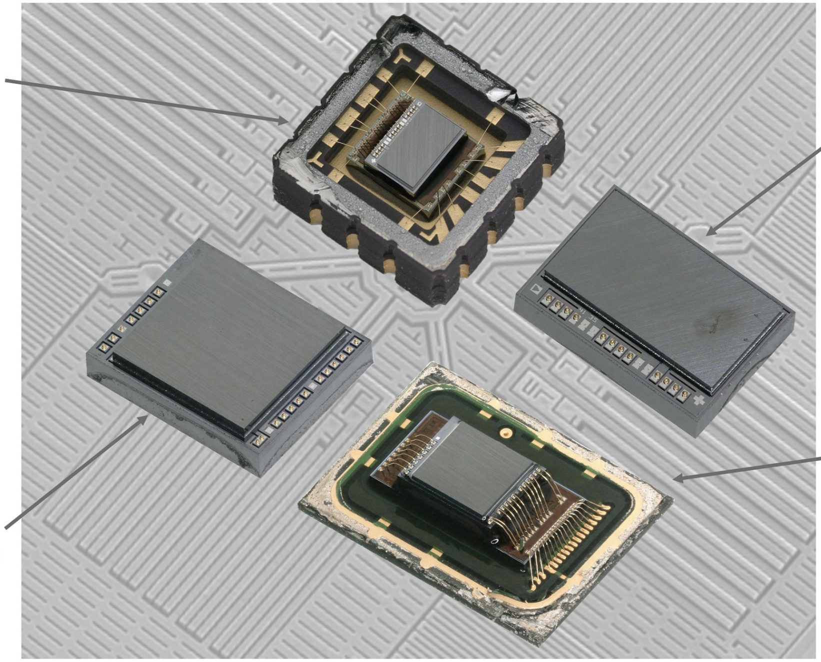
Gyroscope and accelerometer opening – Package, MEMS die and MEMS sensor view

(Source: Analog Devices High-End Accelerometers and Gyroscopes Comparison, System Plus Consulting, 2021)



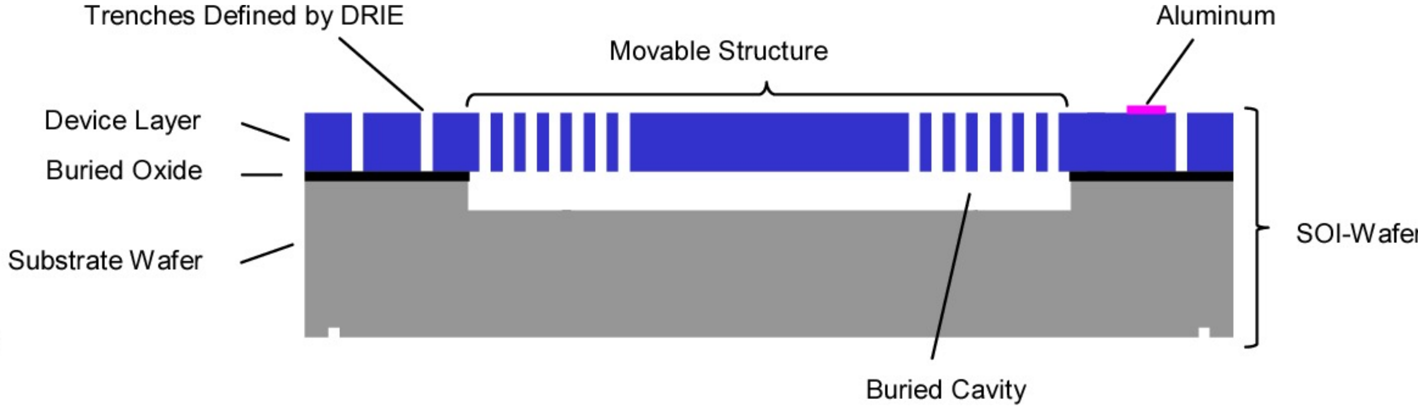
ADXL355B – Package opening view

ADXL355B – MEMS die view

ADXRS295 – Package opening view

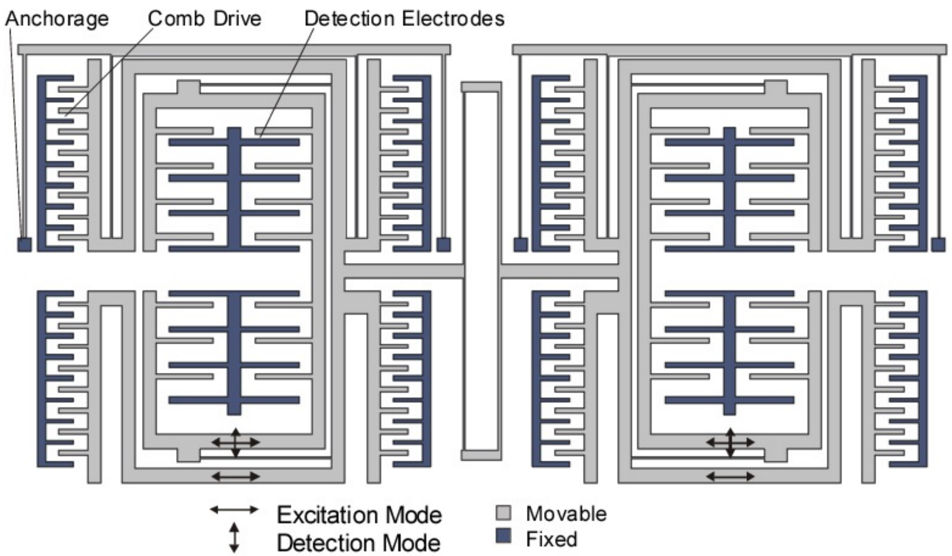
ADXRS295 – MEMS die view

IMU



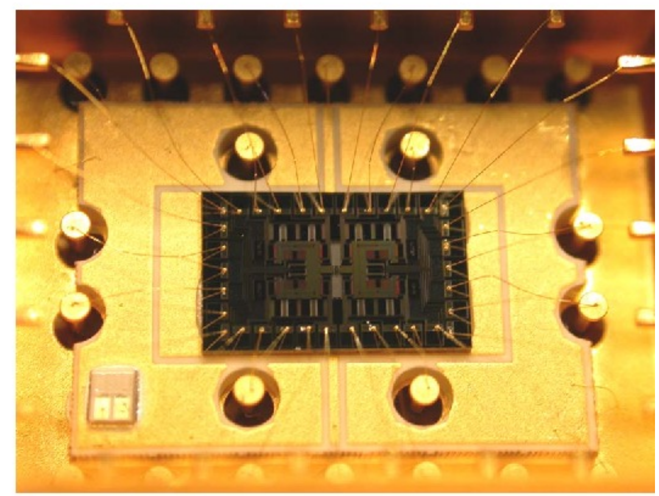
Trenches Defined by DRIE
Movable Structure
Aluminum
Device Layer
Buried Oxide
Substrate Wafer
SOI-Wafer
Buried Cavity

(a)



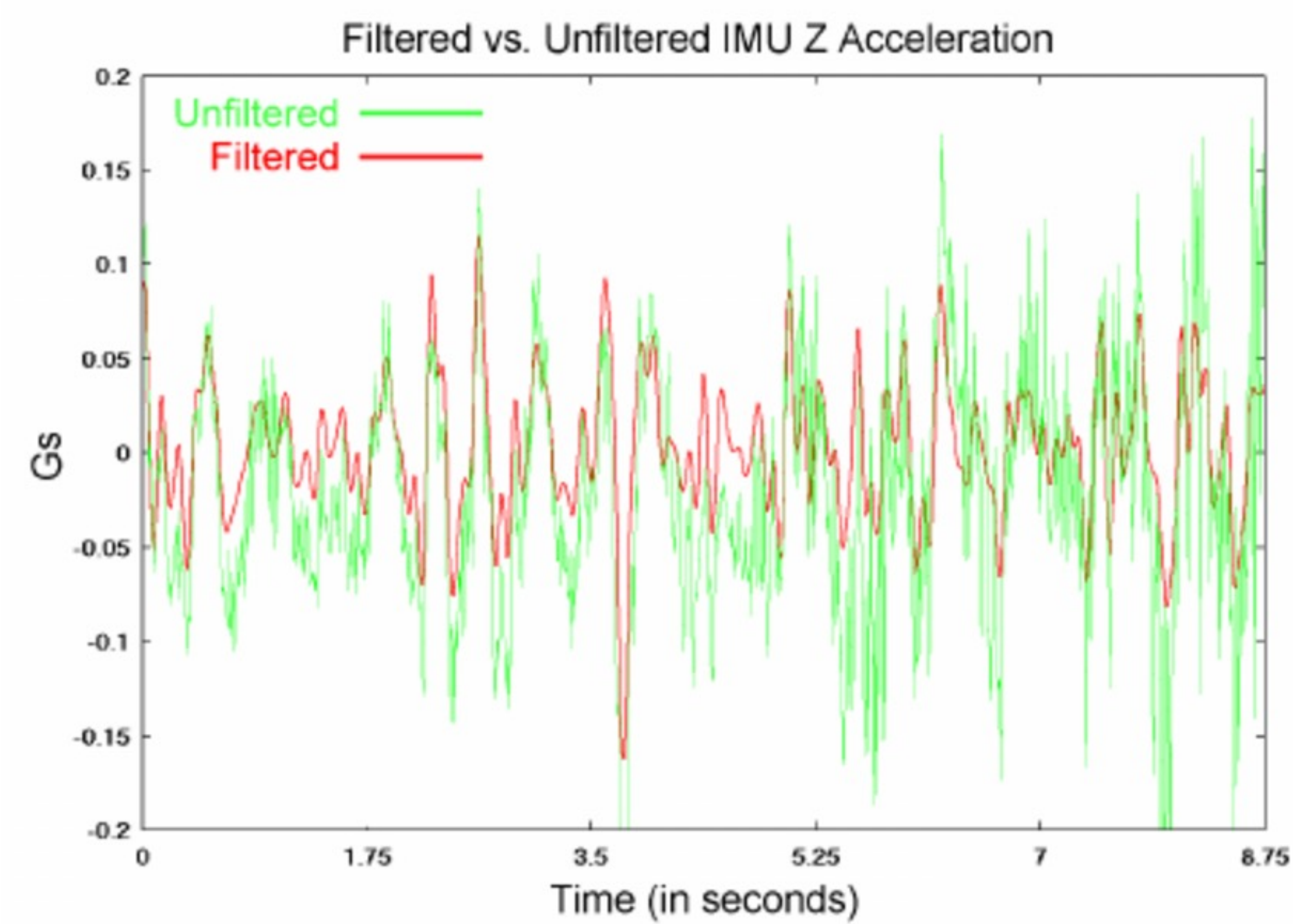
Anchorage
Comb Drive
Detection Electrodes
Excitation Mode
Detection Mode
Movable
Fixed

(b)



(c)

Why Filtering?



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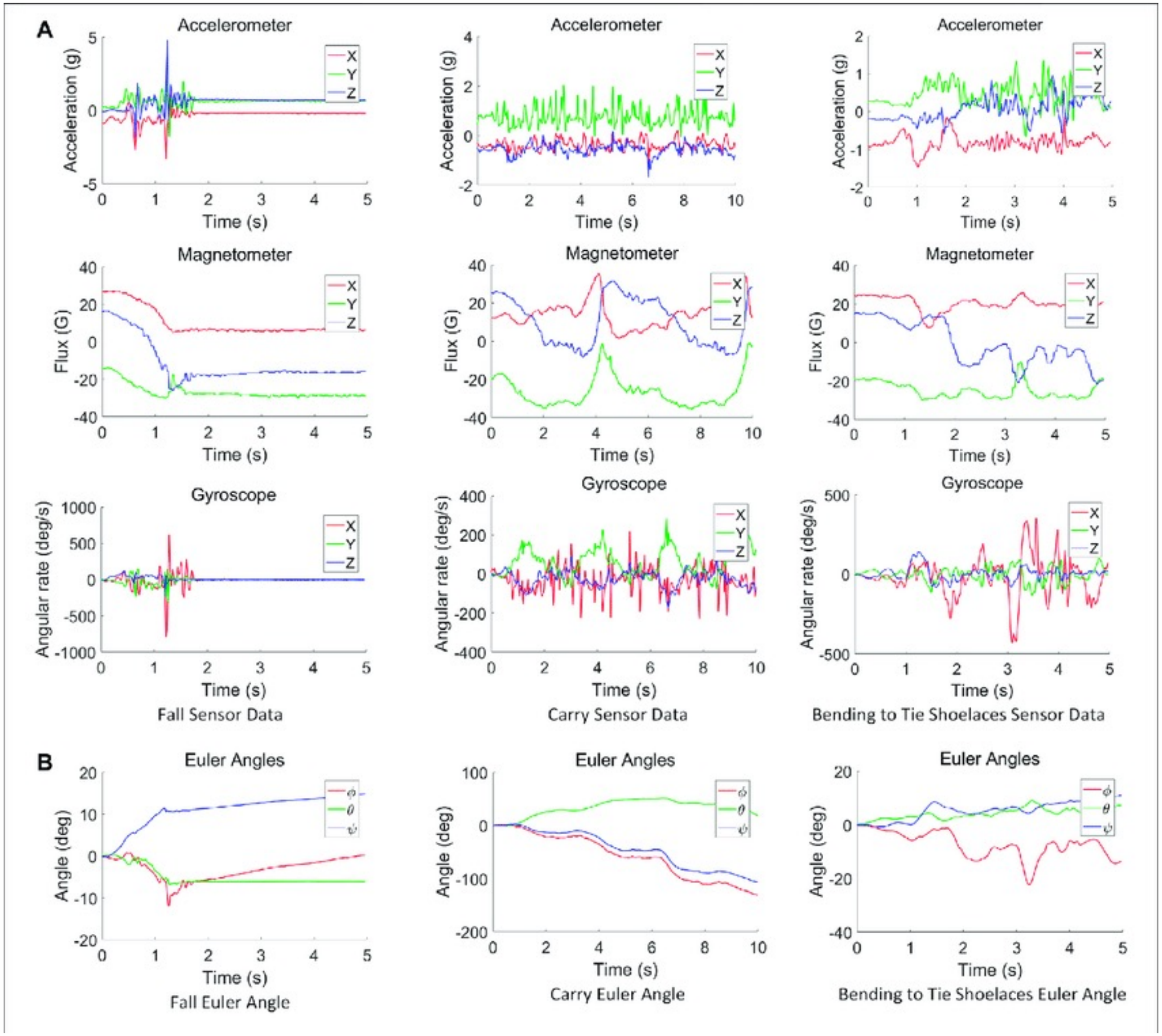
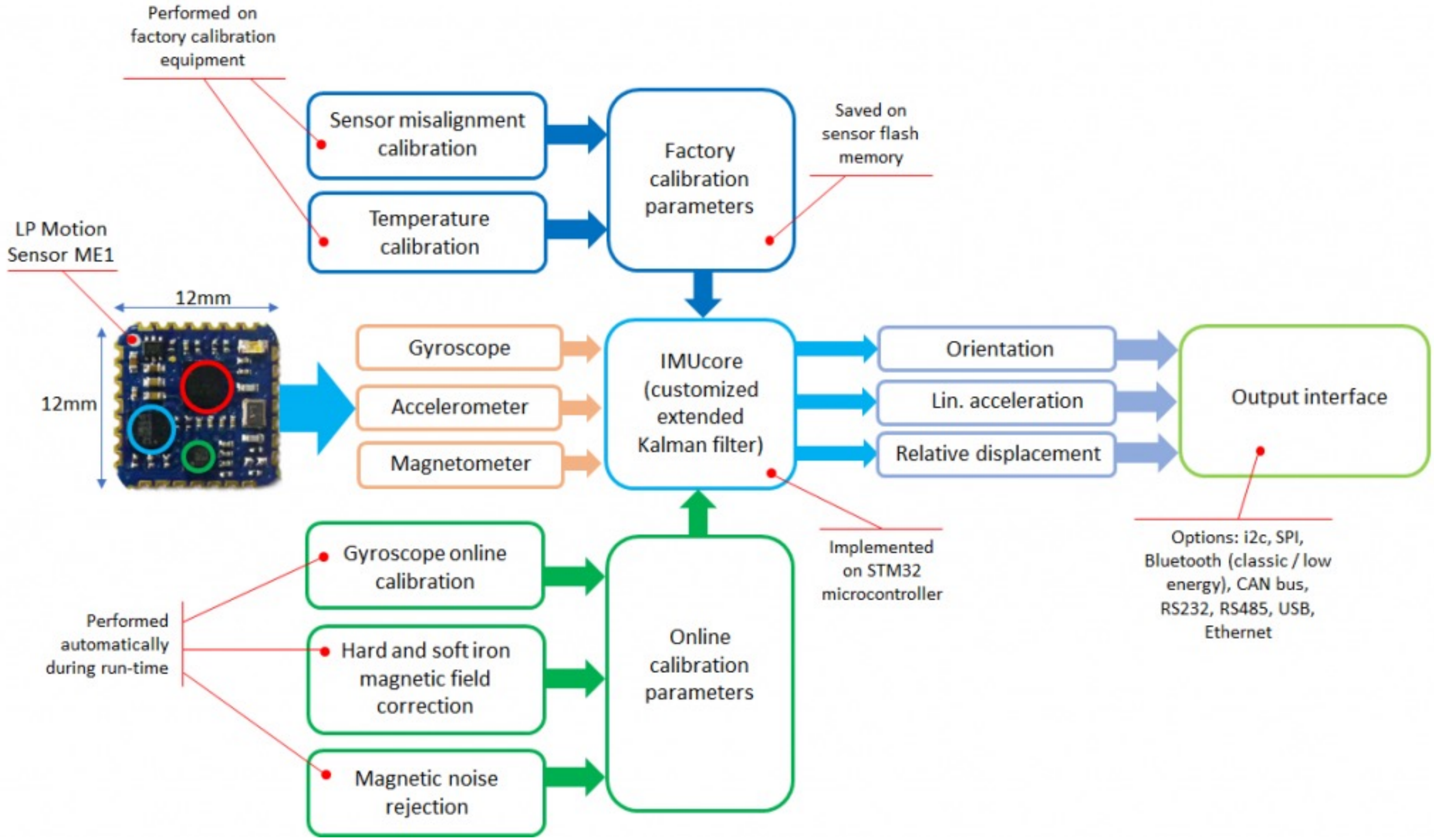
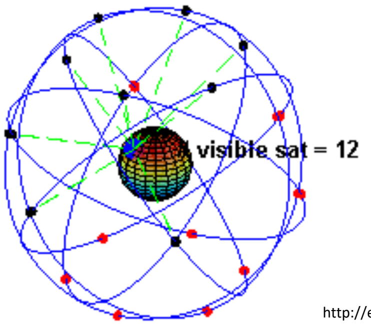


Sensor Fusion



GPS

- 24+ satellites, 12 hour orbit, 20.190 km height
- 6 orbital planes, 4+ satellites per orbit, 60deg distance
- Satellite transmits orbital location (almanach) + time
- 50bits/s, msg has 1500 bits → 12.5 minutes



http://en.wikipedia.org/wiki/File:ConstellationGPS.gif

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GPS

- Position from pseudorange
  - Requires measurements of 4 different satellites
  - Low accuracy (3-15m) but absolute
- Position from pseudorange + phase shift (RTK/dGPS)
  - Very precise (<1mm)
  - Position is relative to a reference station

real time kinematics (RTK)

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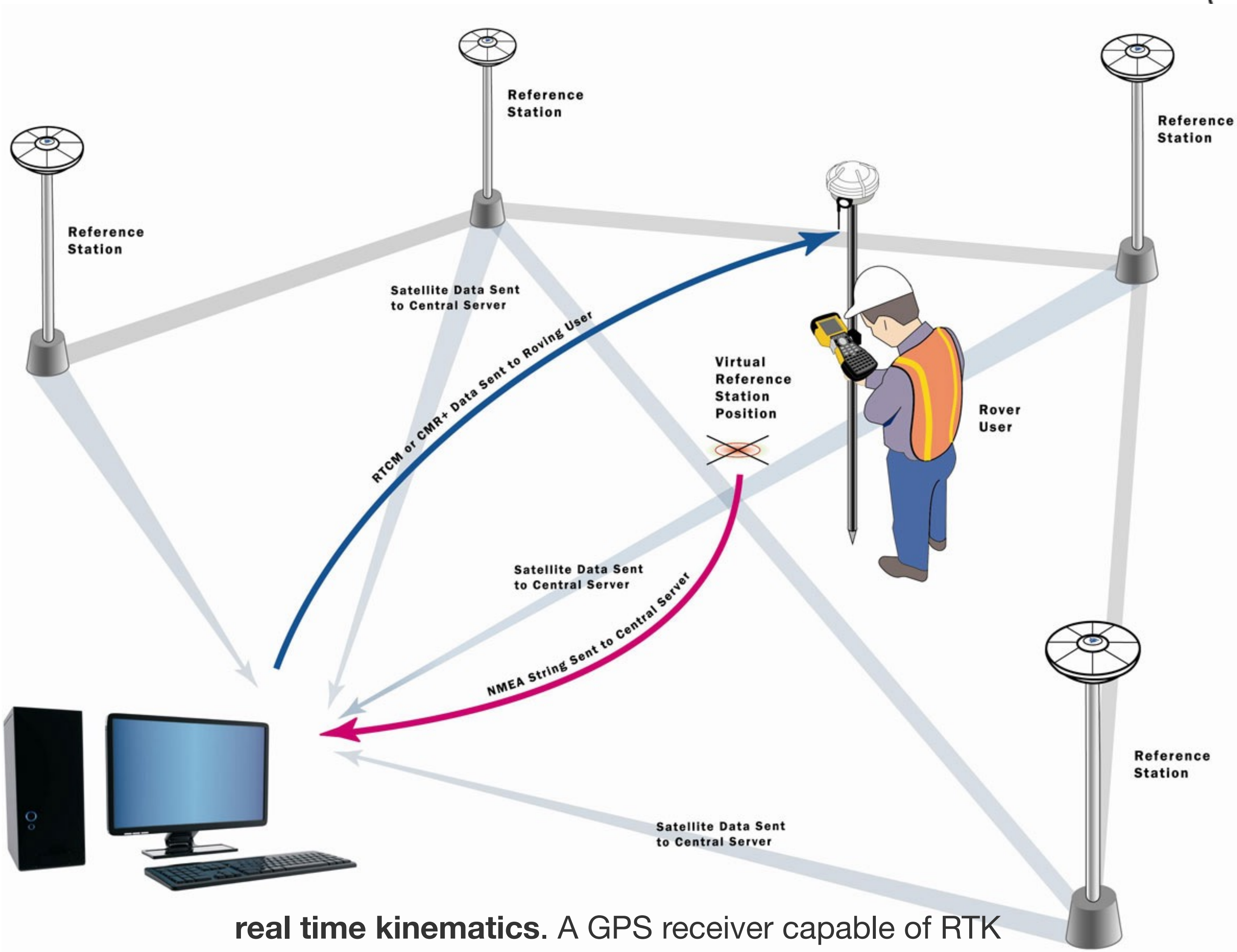
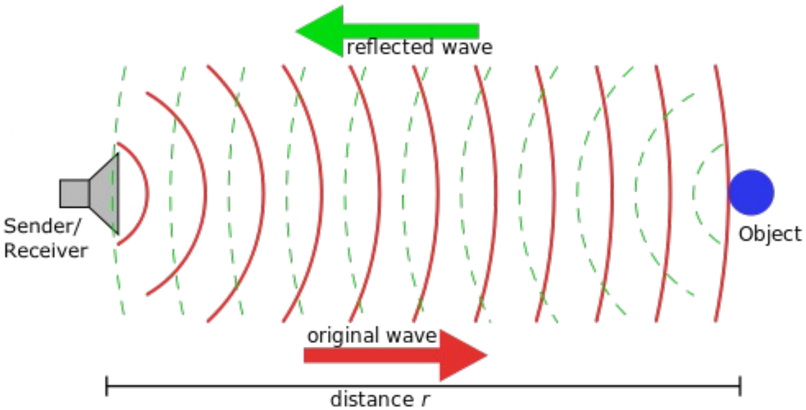


Image courtesy of Trimble

real time kinematics. A GPS receiver capable of RTK takes in the normal signals from the Global Navigation Satellite Systems along with a correction stream to achieve 1cm positional accuracy.

Ultrasound Range Sensors

- Emit signal to determine distance along a ray
- Make use of propagation speed of ultrasound
- Traveled distance is given by speed of sound (v=340m/s)



http://en.wikipedia.org/wiki/File:Sonar_Principle_EN.svg

$$d = \frac{v\Delta t}{2}$$

Ultrasound Range Sensors

- Range between 12cm and 5m
- Opening angle around 20 to 40 degrees
- Problems: multi-path propagation, absorption
- Lightweight and cheap

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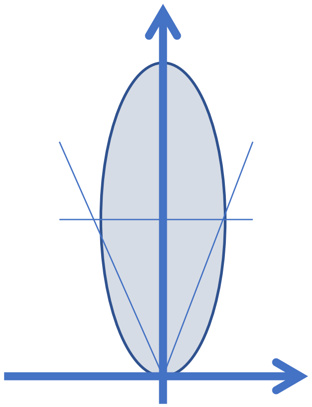
http://www.parallax.com/product/28015



IR Sensors

- Infrared sensors are used to measure distance or proximity.
- Characteristics of IR Sensor
  - Narrow/focused area = high accuracy
  - Don't work in sunlight
  - Can be affected by an object's color

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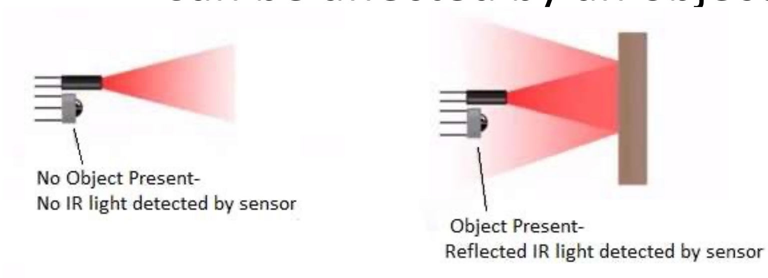
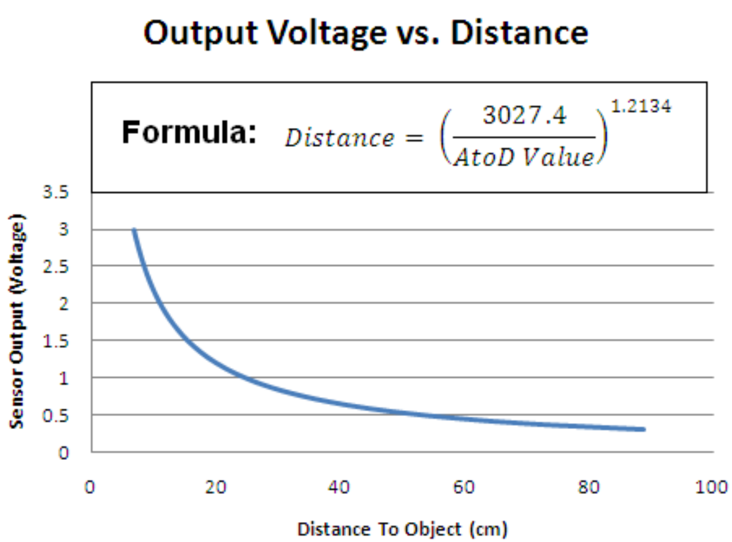
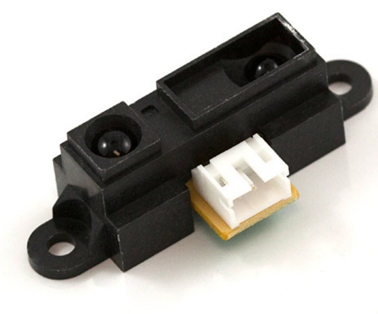




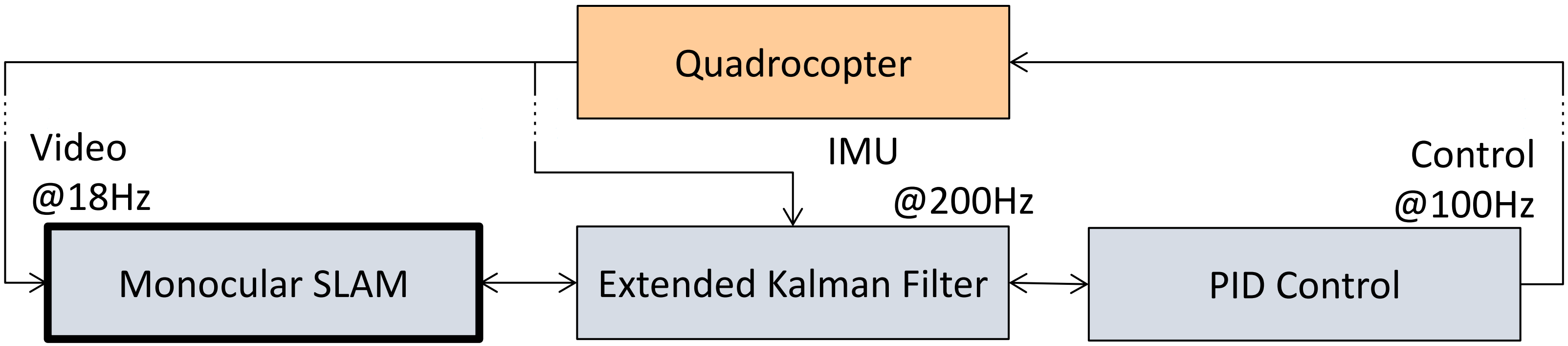


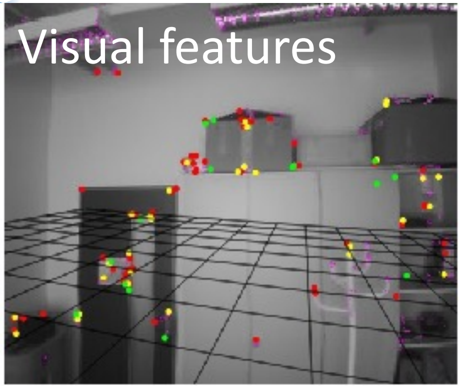
<u>Based on the Type</u>

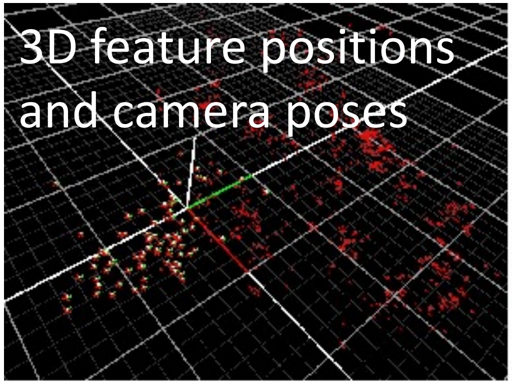
Interface: Analog
Power Supply: 4.5-5.5 Volts
Working Current: 30-50 mA
Distance Range: 10 - 550 cm
Precision: ~1 cm.
Dimensions: 58 x 17.6 x 22.5 mm

Camera-based Navigation

[Engel, Sturm, Cremers; IROS 2012; RAS 2014]







Two Examples

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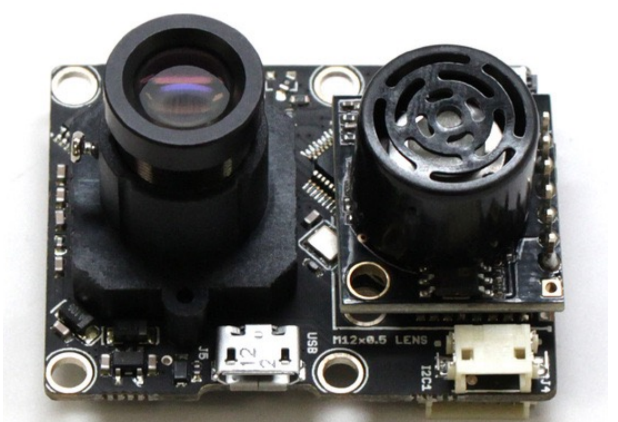
- Parrot Mainboard + Navigation board [Bristeau, IFAC WC 2011]
  Camera + IMU + ultrasound + pressure, 180 USD
- Pix4flow sensor from ETH [Honegger et al., ICRA 2013]
  Camera + IMU + ultrasound, 120 EUR

http://www.parrotshopping.com/us/p_parrot_product.aspx?i=230895

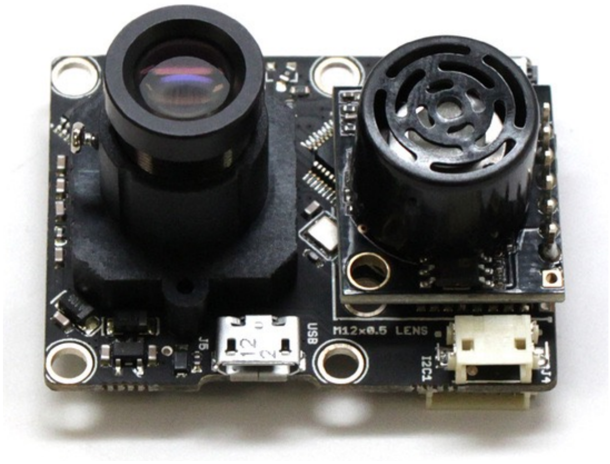


http://pixhawk.org/modules/px4flow

Pix4Flow Sensor

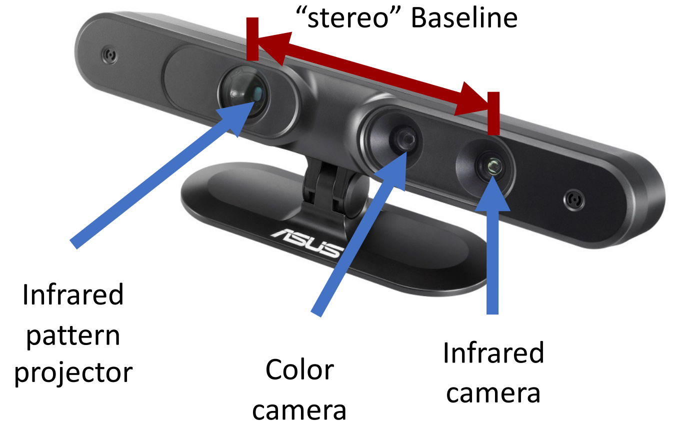
[Honegger et al, ICRA 2013]

- Smart camera module
- 752Hx480V (60fps), 188Hx120V (250fps), 16mm lens
- ARM Cortex M4 (168 MHz, 192 KB RAM, single precision floating point operations)
- MEMS gyroscope (L3GD20)
- Ultrasound sensor
- Outputs speed over serial link
- Open-source



Depth Cameras

- Camera measures depth of every pixel
- Different sensing principles exist
  - Stereo cameras
  - Time-of-flight
  - Structured light (e.g., Kinect)



Lens Distortions

- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens

Camera Calibration

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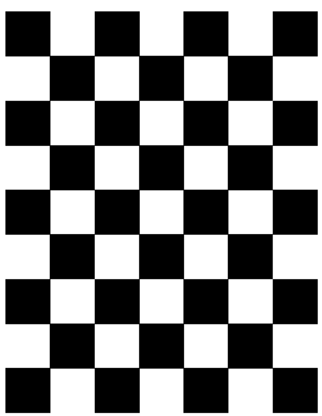
- Collect *n* corresponding observations between
  - 3D points $\mathbf{p}_1, \dots, \mathbf{p}_n$ (3D location in world coordinates)
  - 2D points $\mathbf{x}_1, \dots, \mathbf{x}_n$ (on the image plane)
- Typically using a calibration board



APRIL tags

Autonomy, Perception, Robotics, Interfaces, and Learning

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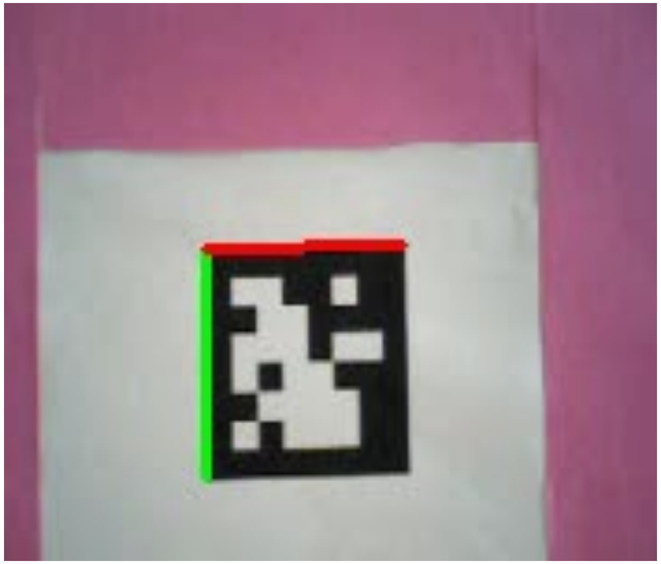
Java-based landmark library from U. Michigan

an example tag in the center...



provides full 6 DOF pose and scale

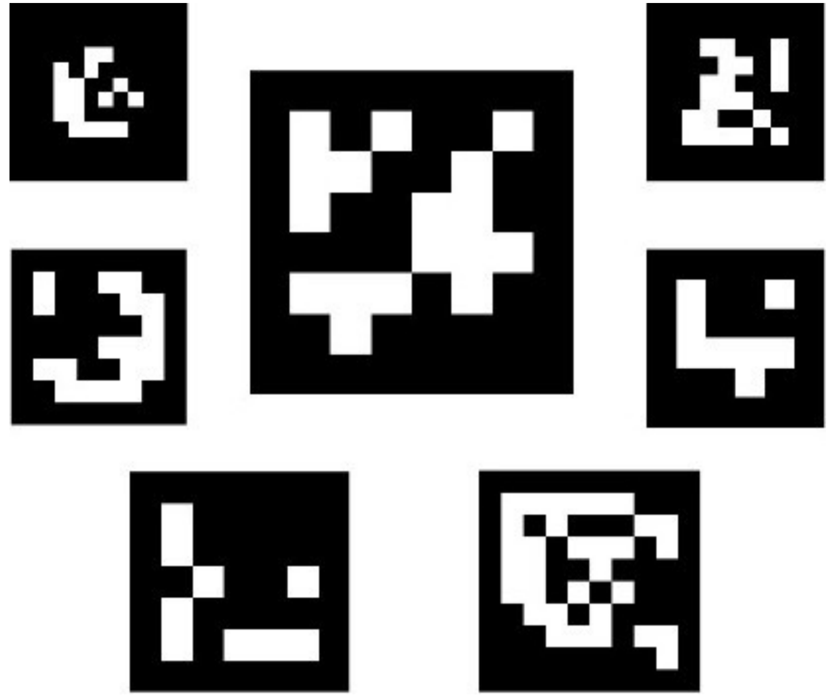
We integrated it into ROS using Python's **os.system** call...

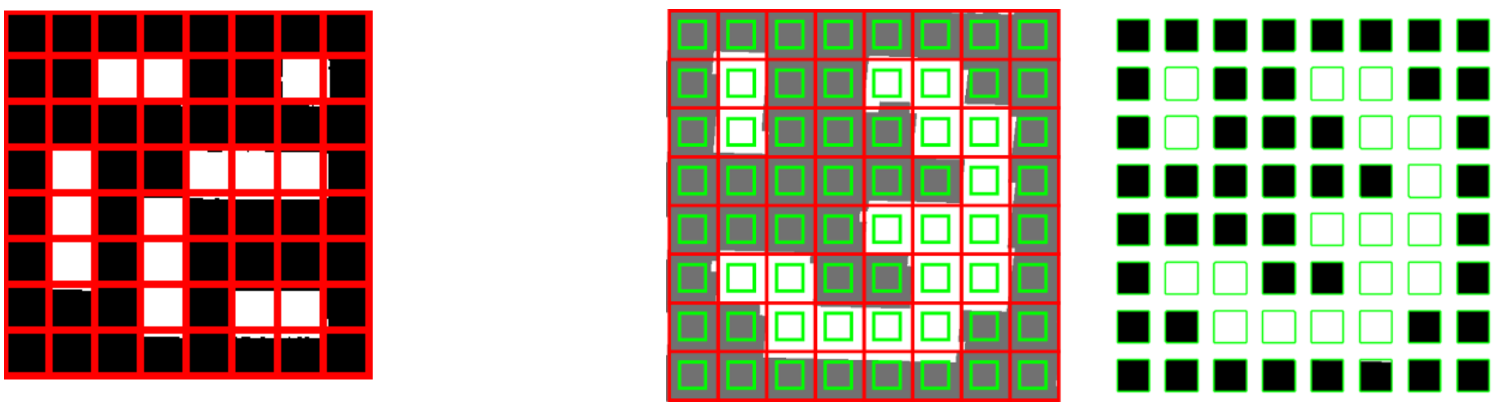
APRIL tags' scale range

an example tag in the center...

provides full 6 DOF pose and scale

ArUco markers





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