sensing & sensors

CMU SCS RI 16722 S2009

MW(& some F) 12:00 -13:20 NSH1305

Onur Ozcan

oozcan@andrew.cmu.edu

+1 412 268 8847

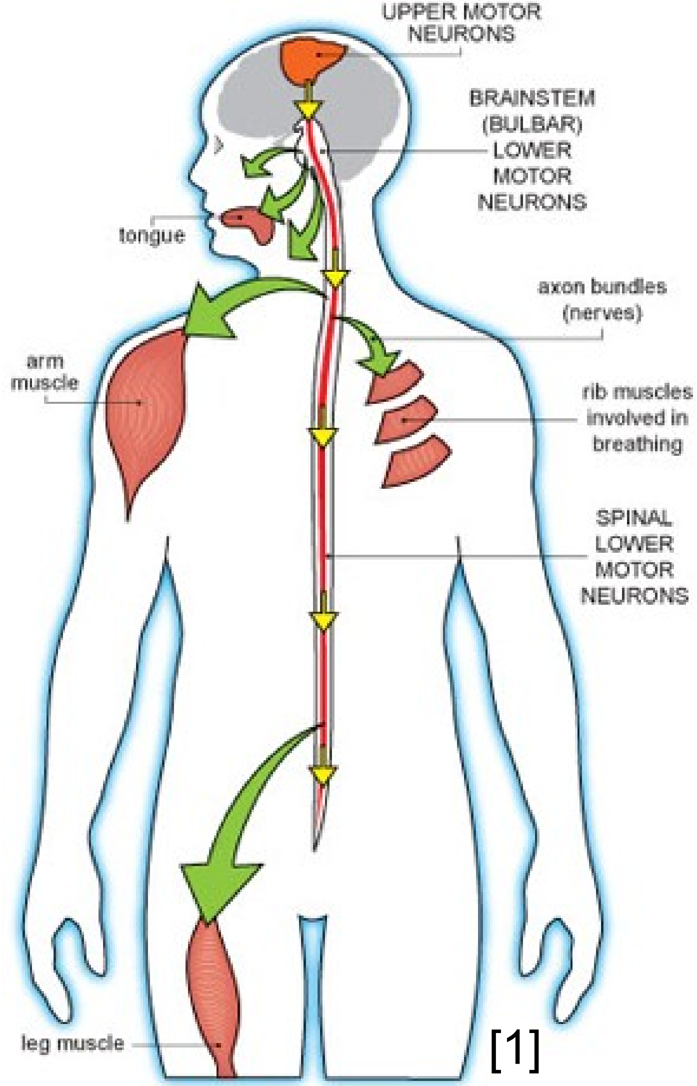
office: SH 423

S2009

Proprioception

Proprioception

- For human:
  - From Latin *proprius*, meaning "one's own" and perception
  - The sense of the relative position of neighboring parts of the body
- For robots:
  - Measure values that are internal to the robot, e.g. motor speed, orientation of the robot, joint angles.



[1]

Why and How?

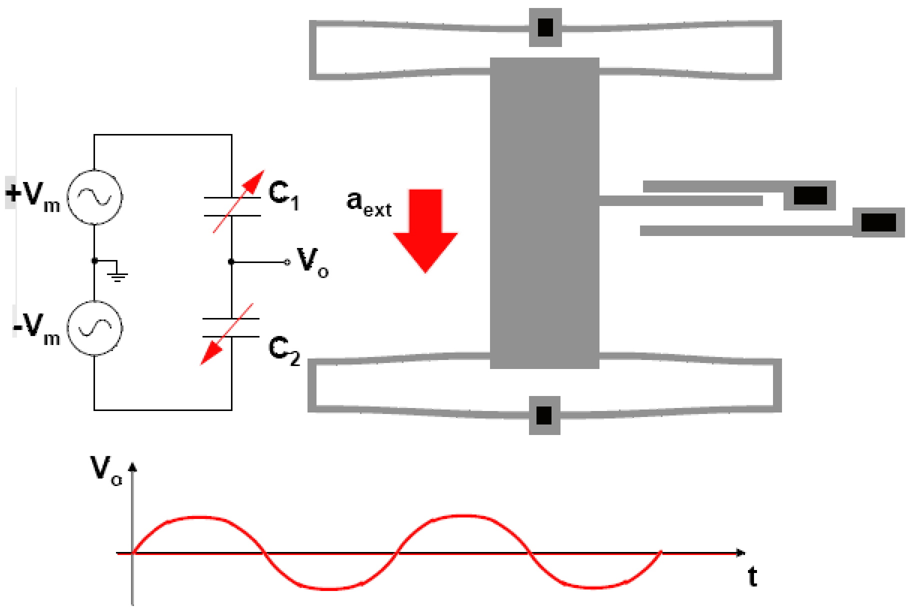
- Proprioception is significant because it enables:
  - Localization
  - Relative positioning
  - Measuring the orientation of the robot

- Proprioception is measured via:
  - Accelerometers
  - Gyroscopes
  - Encoders
  - Strain Gauges
  - Potentiometers

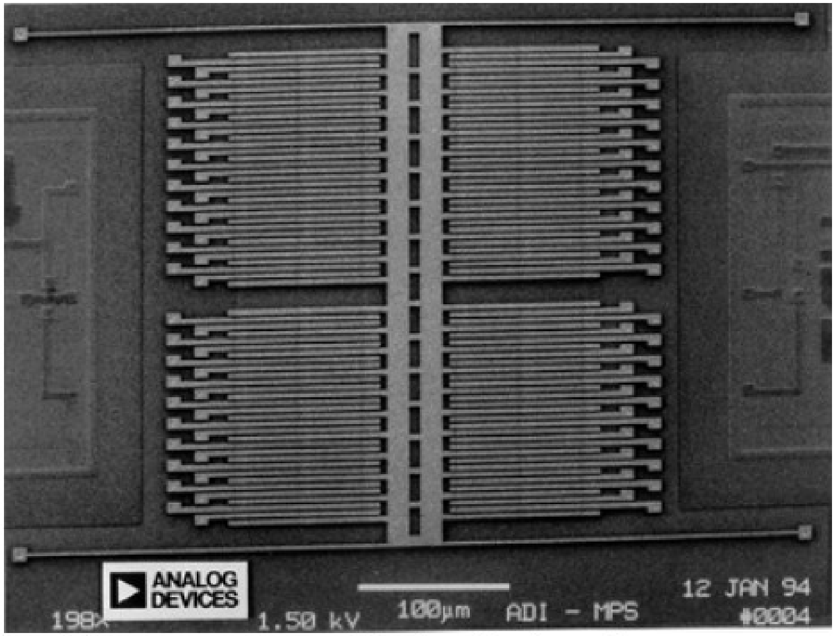
Proprioceptive Sensors #1: Accelerometers

- Calculate position by integrating the measured acceleration twice.
- Calculate forces using $F = ma$
- Usually MEMS devices
- Piezoresistive and capacitive sensing
- A proof mass is connected to springs with known stiffness. The position of the proof mass gives the force, hence the acceleration.
- Should have a significantly lower stiffness in the measurement axis compared to other axes.
- Problem: NOISE!

Proprioceptive Sensors #1: Accelerometers



18614 - F2008: ‘MEMS’ lecture notes

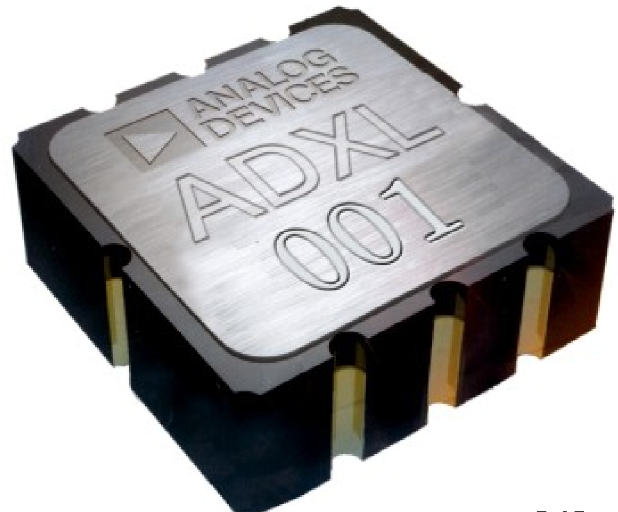


[2] Image courtesy of Analog Devices

Analog Devices ADXL50 50g Accelerometer: First MEMS accelerometer design without a diaphragm

Analog Devices - ADXL001: High Performance Wide Bandwidth MEMS Accelerometer [3]

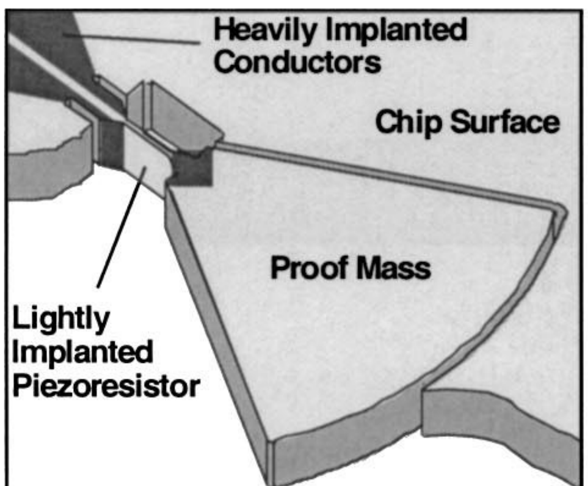
- Specifications:
  - # of Axes: 1
  - Range: +/- 70g
  - Sensitivity: 24.2 mV/g
  - Output Type: Analog
  - Typical Bandwidth (kHz): 22kHz
  - Voltage Supply (V): 3.135 to 6
  - Supply Current: 9mA
  - Temp Range (°C): -40 to 125°C
  - High linearity: 0.2% of full scale
  - Low noise: 4 mg/√Hz
  - Price: $35.04

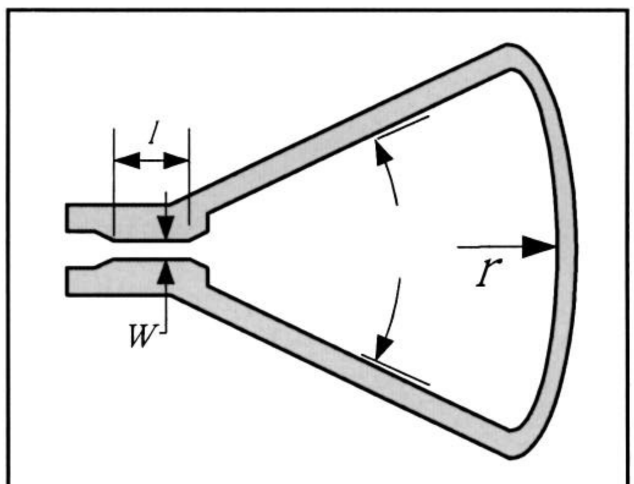


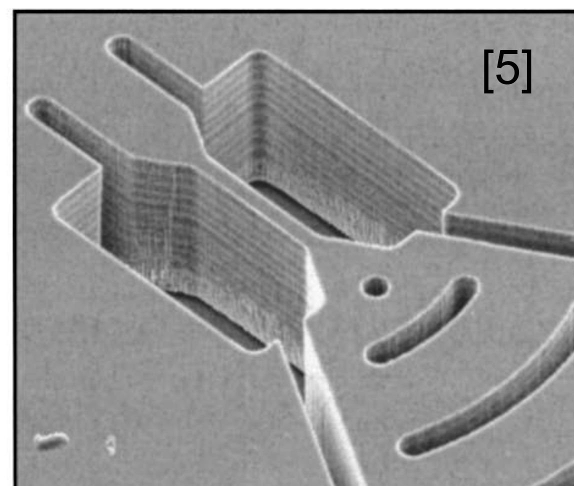
[4]

Piezoresistive Accelerometers

- Works nearly the same as capacitive accelerometers.
- The deflection of the proof mass is measured by a piezoresistive element.
- Usually more non-linear and suffer from hysteresis. Often less sensitive than capacitive accelerometers







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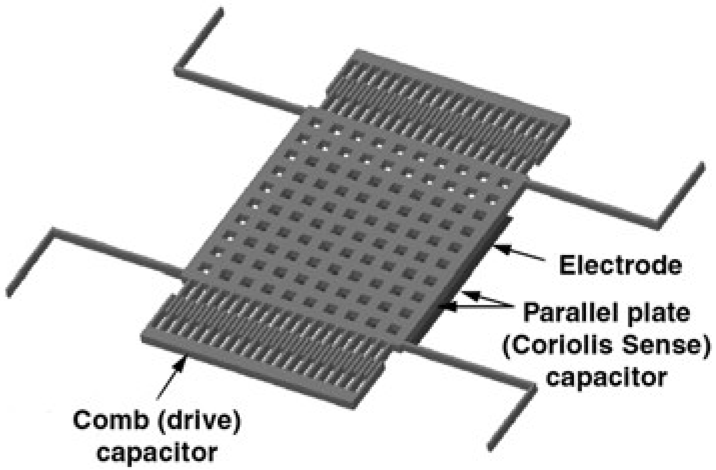
Endevco Model 7264: Piezoresistive Accelerometer

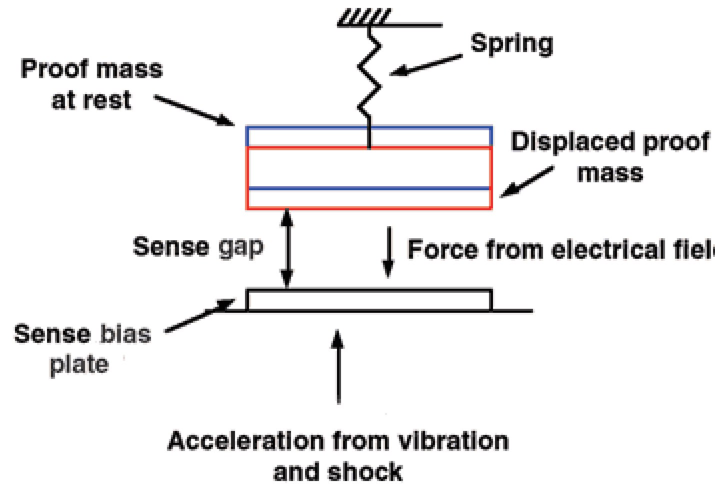
Dynamic characteristics	Units	7264D-2000
Range	g	± 2000
Sensitivity (at 100 Hz & 10 g)	mV/g typ	0.20
	(min)	(0.15)
Frequency response	Hz	
(± 2% max, ref. 100 Hz)		0 to 3000
(± 5% max, ref. 100 Hz)		0 to 6000
Mounted resonance frequency	Hz typ	> 40 000
Damping ratio	Max	0.005
Non-linearity		
(% of reading, to full range)	% max	± 1
Zero repeatability		
(after full scale shock)	Equiv. g	0.2
Transverse sensitivity	% max	1
Zero measurand output	mV max	± 25
Thermal zero shift	mV typ	± 10
From 0˚F to +150˚F (-18˚C to +66˚C), ref 75˚F (24˚C)	mV max	± 25
Thermal sensitivity shift	%/˚F typ	-0.06
From 0˚F to +150˚F (-18˚C to +66˚C)	%/˚C typ	-0.10
From 65˚F to +85˚F (+18˚C to +29˚C), ref 75˚F (24˚C)	± % typ	1.0
Warm-up time	ms max	1
Base strain sensitivity (per ISA 37.2 @ 250 μ strain)	Equiv. g's	< 0.1
Mechanical overtravel stops	g's	5000 g typical, 2500 g minimum

[6]

Proprioceptive Sensors #2: Gyroscopes

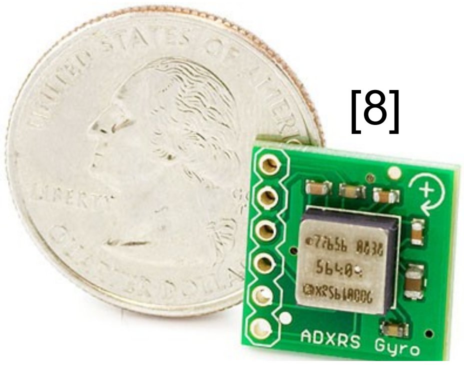


[7]



- Gyroscope is oscillated in horizontal plane
- The Coriolis force due to angular rotation causes the proof mass to oscillate in vertical direction
- Problems: Noise, nonlinearity and possible failure with high forces

Analog Devices - ADXRS610: ±300°/sec Yaw Rate Gyro



[8]

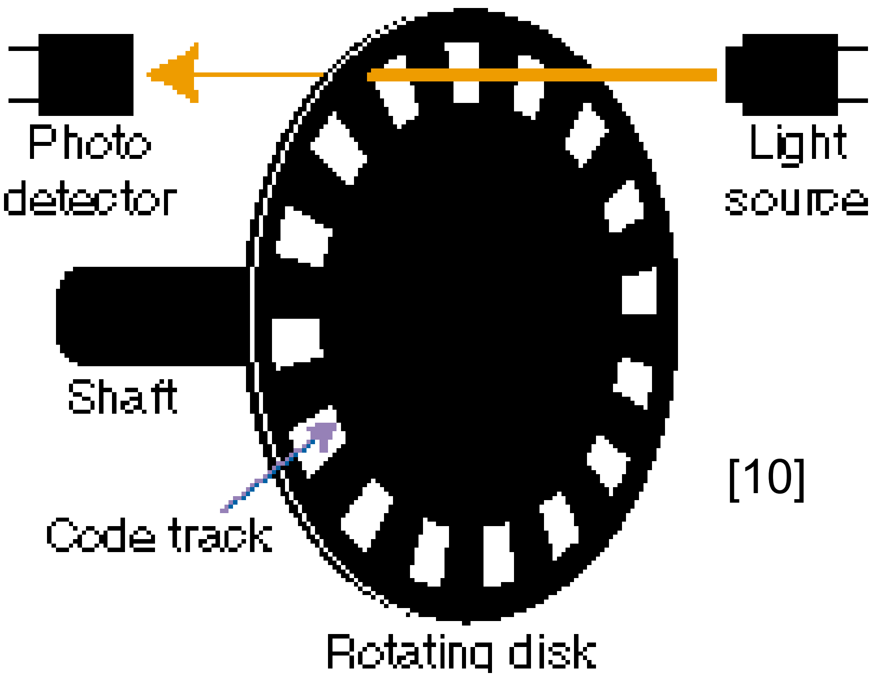
- Complete rate gyroscope on a single chip
- Z-axis (yaw rate) response
- High vibration rejection over wide frequency
- Low-cost (Price: $19.98)

[9]

Parameter	Conditions	ADXRS610BBGZ			Unit
		Min	Typ	Max	
SENSITIVITY[1]	Clockwise rotation is positive output				
Measurement Range[2]	Full-scale range over specifications range	±300			°/sec
Initial and Over Temperature	−40°C to +105°C	5.52	6	6.48	mV/°/sec
Temperature Drift[3]			±2		%
Nonlinearity	Best fit straight line		0.1		% of FS
NULL[1]					
Null	−40°C to +105°C	2.2	2.5	2.8	V
Linear Acceleration Effect	Any axis		0.1		°/sec/*g*
NOISE PERFORMANCE					
Rate Noise Density	$T_A \leq 25°C$		0.05		°/sec/√Hz
FREQUENCY RESPONSE					
Bandwidth[4]		0.01		2500	Hz
Sensor Resonant Frequency		12	14.5	17	kHz

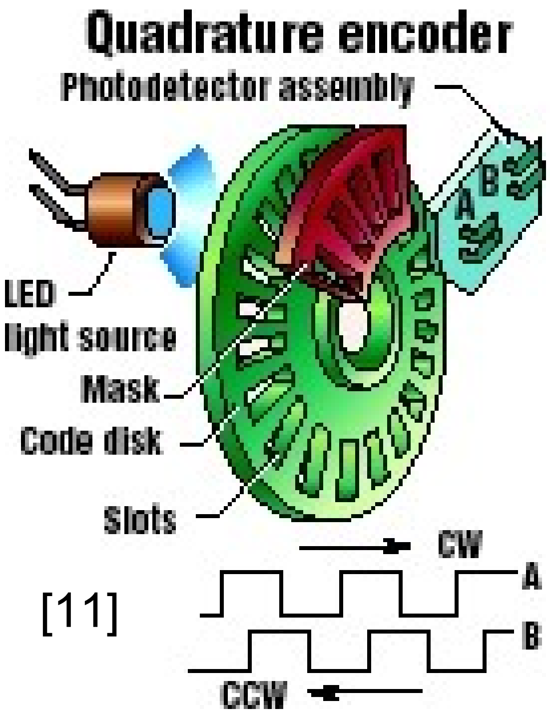
Proprioceptive Sensors #3: Encoders

- Measures angular displacement of a motor shaft.
- 3 different types: Incremental, quadrature and absolute.
- There are also magnetic ones that work essentially the same

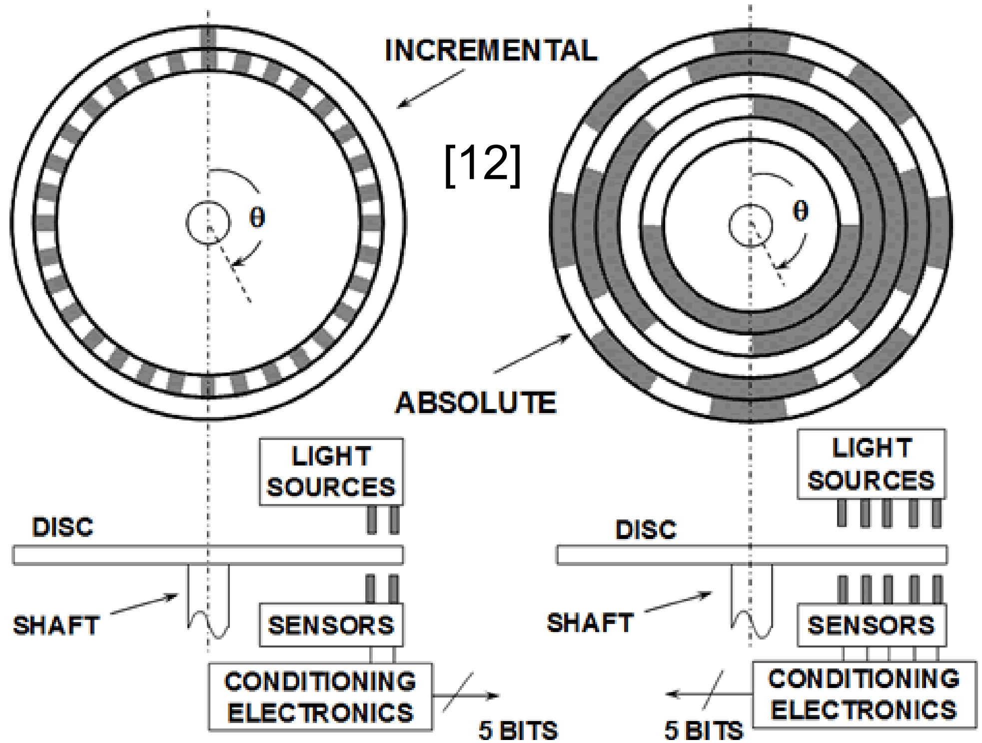


[10]

Proprioceptive Sensors #3: Encoders



[11]

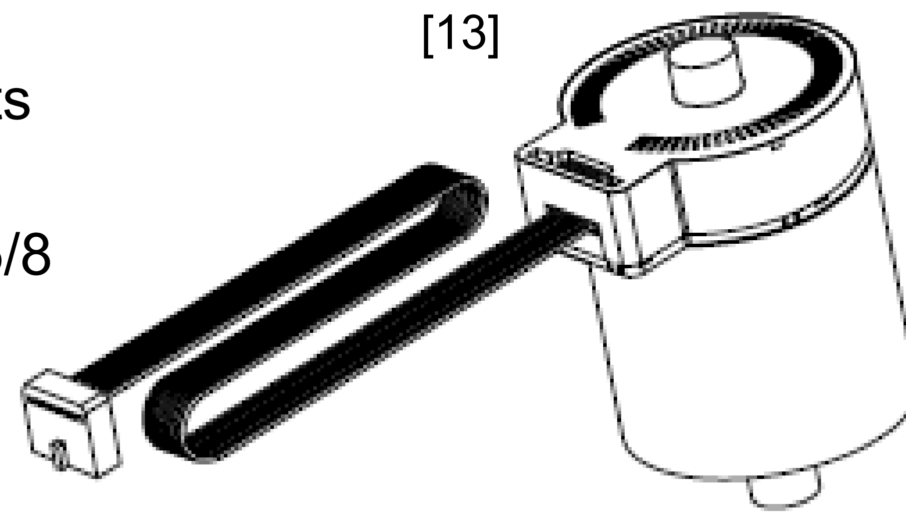


Maxon Encoder
HEDL 65xx/ HEDS 65xx Series

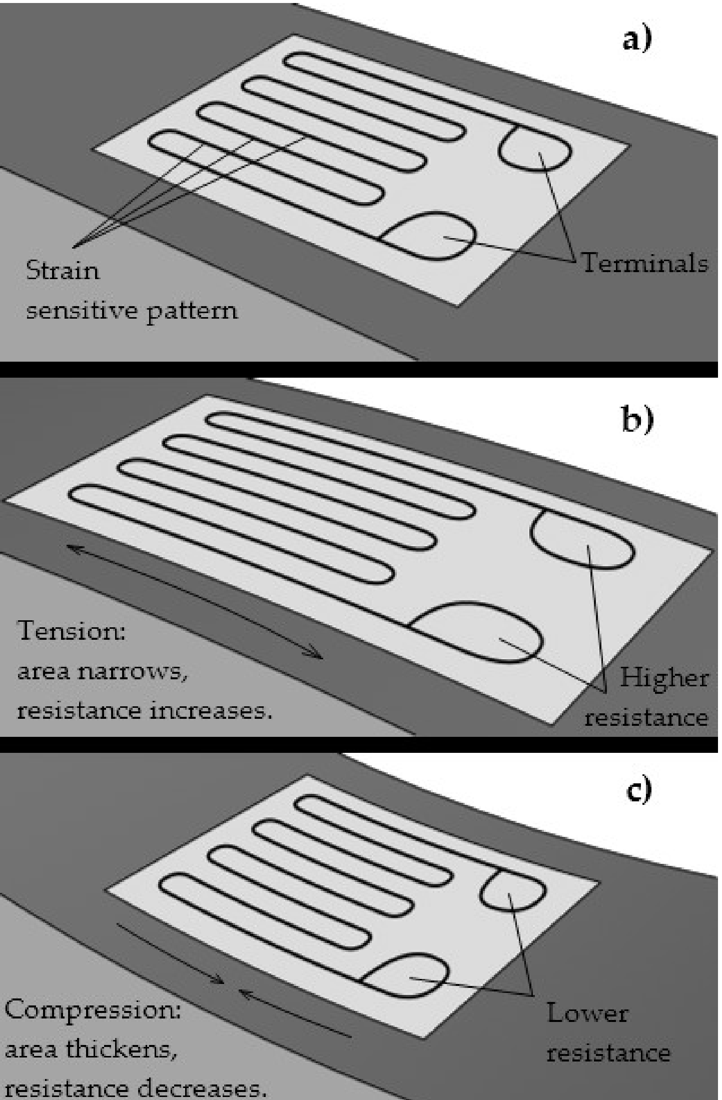
Features:

- Two Channel Quadrature Output with Optional Index Pulse
- 100°C Operating Temperature
- Easy Assembly, No Signal Adjustment Necessary
- Resolutions up to 1024 Counts Per Revolution
- Maximum Shaft Diameter of 5/8 Inches
- Single +5 V Supply

[13]



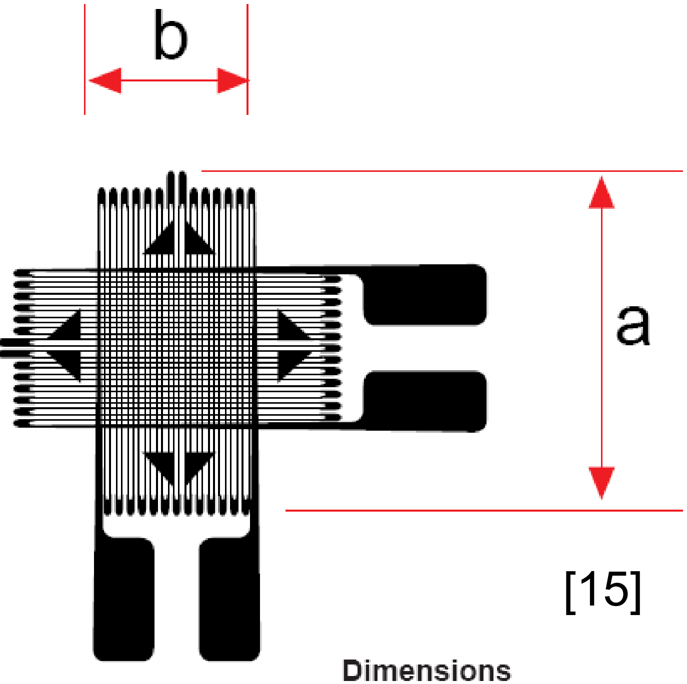
Proprioceptive Sensors #4: Strain Gauges



[14]

- Deflects with strain, changes resistance
- Is measured with Wheatstone bridges
- Is often used in accelerometers (Not MEMS) or linear actuators as feedback or measurement devices.
- Can be used in an analogous way to human receptors in muscles.

Omega - XY SERIES
BIAXIAL GAGES FOR AXIAL STRAIN



[15]

a = 7 mm

b = 3.5 mm

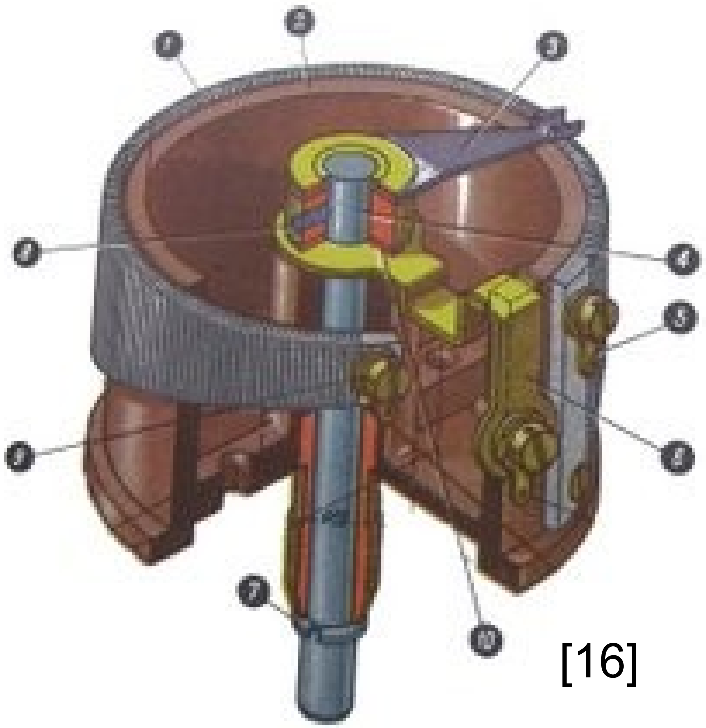
Package Price = 5 x $30

Foil Thickness:5 µm
Carrier Material: Polyimide
Carrier Thickness: 50 µm
Connection: Solder pads, solder dots
Nominal Resistance: 350 and 1000 Ohms
Resistance Tolerance: 0.5%
Gage Factor: 2.0 nominal (actual value printed on each package)

Thermal Properties
Reference Temp.: 23°C/73°F
Service Temp:
Static: -30 to 250°C (-22 to 482°F)
Dynamic: -30 to 300°C (-22 to 572°F)
Compensated Temp.: -5 to 120°C (5 to 248°F)
Tolerance of Temp. Comp.: 1 ppm°C (0.5 ppm°F)

Mechanical Properties
Maximum Strain: 3% or 30,000 µe
Fatigue (at ±1500 µe): > 10,000,000 cycles
Smallest Bending Radius: 3 mm (1 /8 inch)

Proprioceptive Sensors #5: Potentiometers



[16]

- A variable resistor that is commonly used as a sensor.
- Changes contact point of wiper with rotation; therefore changes resistivity.
- High voltage output
- Can be used as a rotation sensor
- Can sometimes be used as throttle position sensor for automobiles. (Toyota uses this kind of control) [17]

Honeywell - 114BF1A102: Conductive Plastic Potentiometers

- Potentiometer Type: Precision
- Element Type: Conductive Plastic
- Terminal: Turret
- Power Rating: 1 W
- Resistance Value: 1 kOhm
- Resistance Tolerance: ± 10 %
- Linearity: ± 1 %
- Shaft Diameter: 6,35 mm [0.25 in]
- Body: 33,53 mm [1.32 in} diameter, ± 21,72 mm [0.855]
- Electrical Taper: Linear
- Operating Temperature: -65 °C to 125 °C [-85 °F to 257 °F]
- Rotational Life: 10 million cycles
- Mechanical Rotation: 360°

[18]

Assignment

- Compare a wheeled robot and a legged robot in terms of their needs for proprioceptive sensors, and their priorities. Comment on:
  - What are the key issues for a wheeled robot?
  - What type of proprioceptive sensors are needed for solving these issues?
  - What are the key issues for a legged robot?
  - What type of proprioceptive sensors are needed for solving these issues?

Research & Applications

- Nearly all robots (especially exploratory robots) uses proprioceptive sensors

- Proprioceptive sensors are well-established.
  - Noise level of accelerometers are a problem and being investigated by MEMS companies.
  - Miniaturization of Gyros are still being investigated, some products are already in the market.
  - <u>Researchers:</u> MEMS companies like Honeywell, Bosch, Analog Devices, ST Microelectronics.

Research

- Usually used for biomedical research
  - Prosthetic arm, defining joint positions…etc.

- Noise level of accelerometers are a problem and being investigated by MEMS companies.
- Sensor Fusion: Enables relative and absolute positioning.
- Error correction/compensation: Usually using Kalman Filters or other drift estimation techniques.

Some Applications

[19] 

- Versatile Stair-Climbing Robot for Search and Rescue Applications – Bremen Germany, 2008
- Proprioceptive control approach is employed.
- Motor torque sensors and a tilt sensor is used
- Each leg is controlled independently using torque and tilt feedback

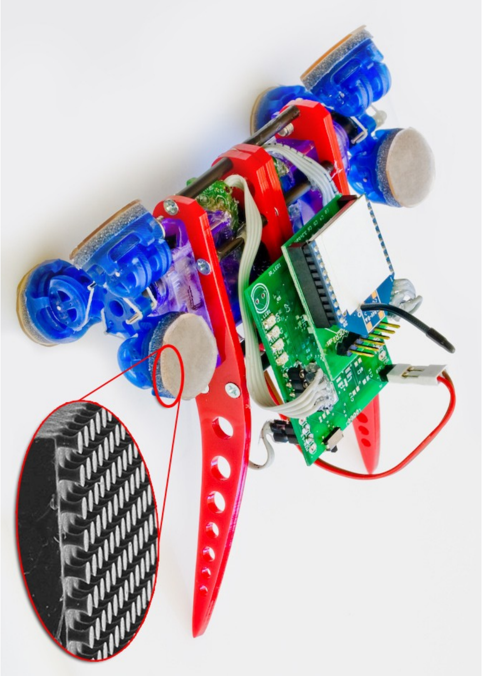
[20] 

- Spirit – NASA, 2007
- Still exploring Mars
- Inertial measurement unit, act analogous to inner ear of human
- Can make precise movements
- Can work in a high range of temperatures

Some Applications from CMU

[21] 

- Scarab – RI CMU, 2009
- Lunar Crater Exploration
- Have inertial sensors, ground speed sensors, laser proximity sensors and a drill (which would need more proprioceptive sensors)
- It uses sensor fusion effectively to navigate

[22] 

- WaalBot – Nanorobotics lab, MechE CMU, 2007-Still on going.
- Uses accelerometers for orientation determination
- Uses motor encoder information to be able to climb. (force transfer is very important when climbing)

Future Directions

- Lower noise levels: With the rise of micro/nano technology, the noise levels of inertial measurement units will decrease.
- Sensor Fusion: The help of sensor fusion field will enable the proprioception sensors create absolute position data with the help of GPS (absolute coordinates) and/or compasses (direction).
- Software error correction for proprioceptive sensors: Several groups are working on this subject to decrease or eliminate the errors due to the high noise levels of inertial measurement units. They are expected to find solutions soon.

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