Friedrich-Alexander University
Erlangen-Nuremberg

Sensors for Intent Detection

Sensors

US

FMG

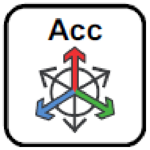
IMU

EIT

force / torque

sEMG / EMG

IMU



$\left[{}^{m}/_{s^2}\right]$

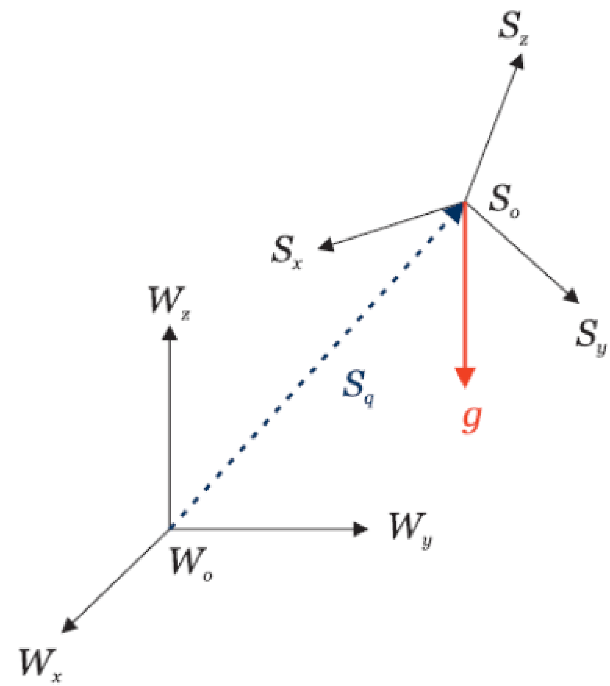
Accelerometer

$\left[{}^{\circ}/_{s}\right]$

Gyroscope

(+Magnetometer)

Orientation



Own representation based on (Kuipers, 1999)

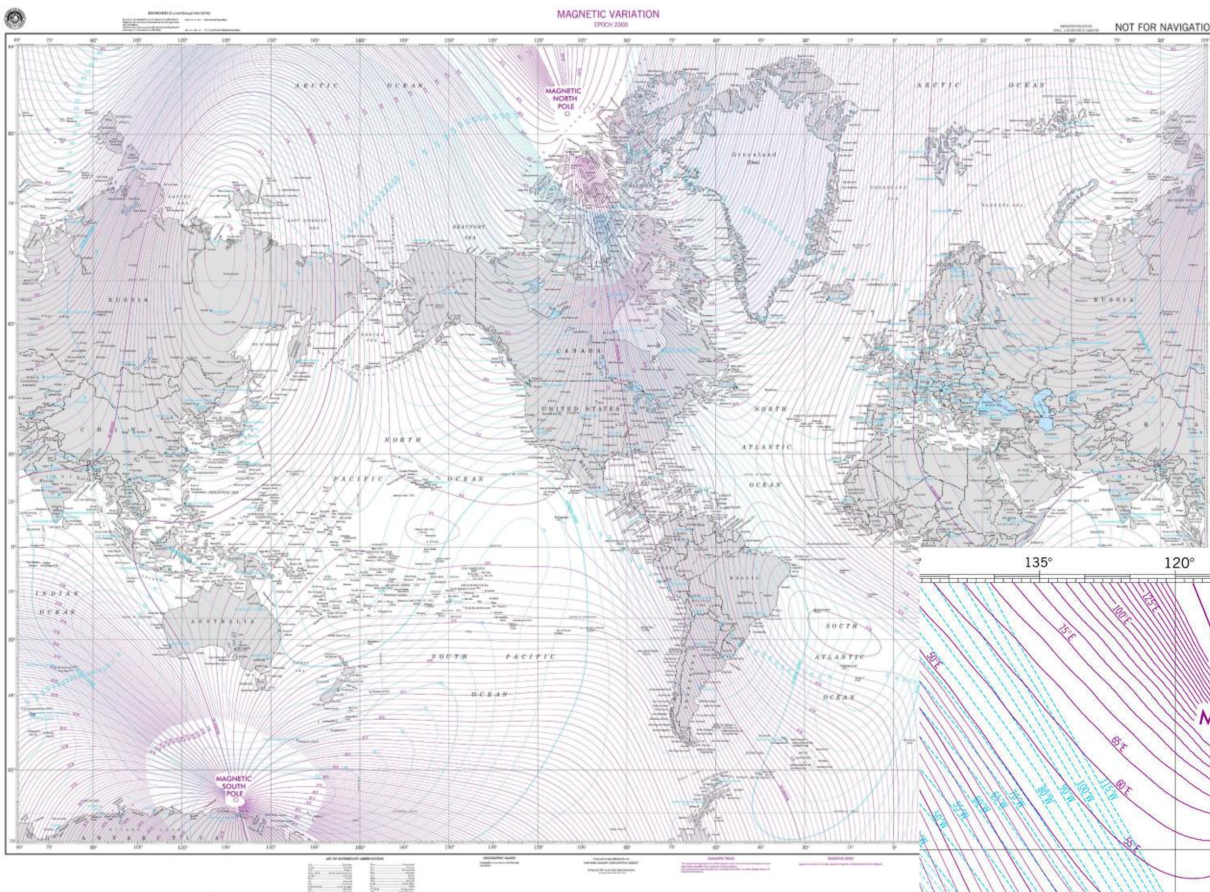
Icons are based on https://portabiles.de/portfolio/nilspod/

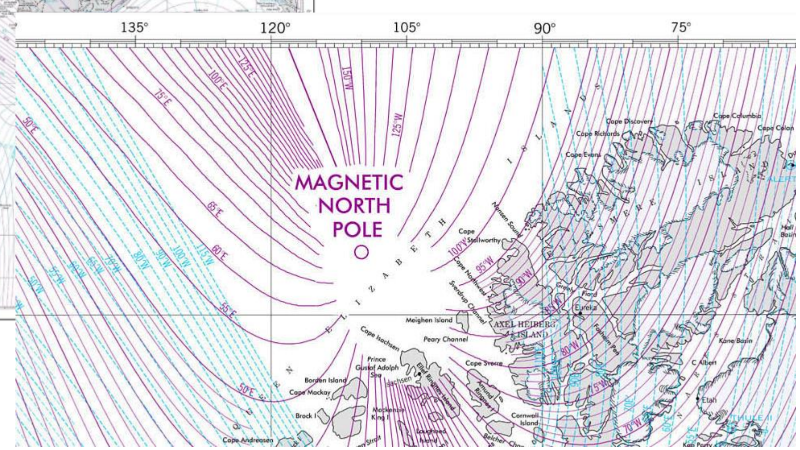
IMU

https://www.youtube.com/watch?v=0kgw_P5q9_o

What happens to magnetometer, if you are at the north pole?
At the magnetic North Pole, the magnetic field lines are vertical, pointing directly downwards into the Earth. The horizontal component of the magnetic field (parallel to the Earth's surface) is essentially zero. The magnetometer might produce unstable or rapidly fluctuating directional readings because it cannot reliably detect a stable horizontal field.

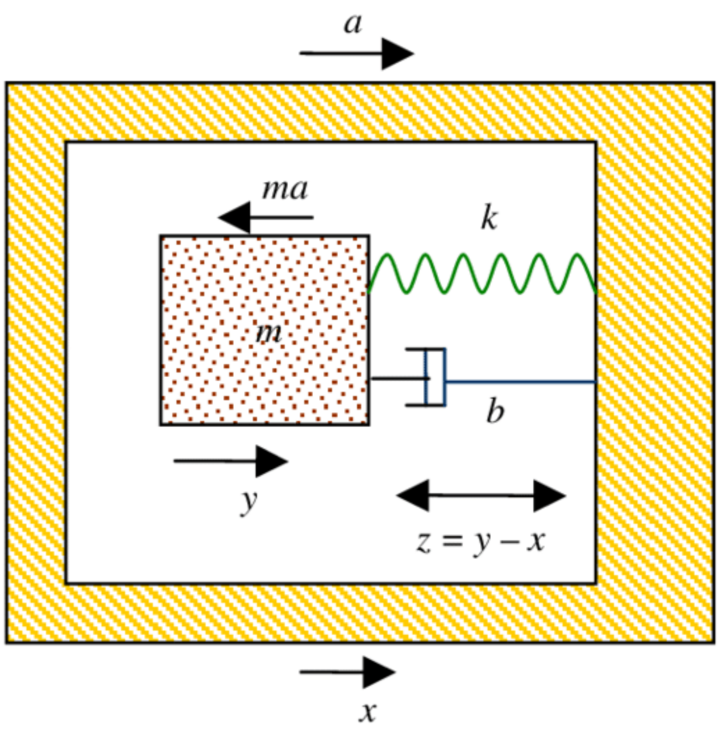
What could disturb a magnetometer?
Electromagnetic Interference
Magnetic materials
Metal Objects - Distorted Readings: - ferromagnetic materials magnetized



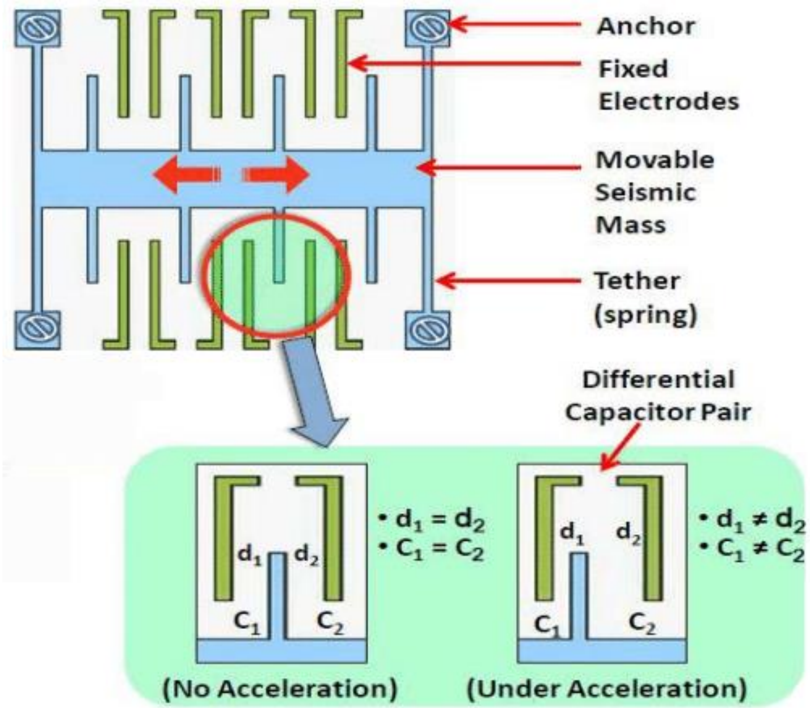


https://upload.wikimedia.org/wikipedia/commons/2/28/Mv-world.jpg

IMU



Krishnan, Girish et al. "Micromachined High-Resolution Accelerometers." *Journal of the Indian Institute of Science* 87 (2007): 333-360.



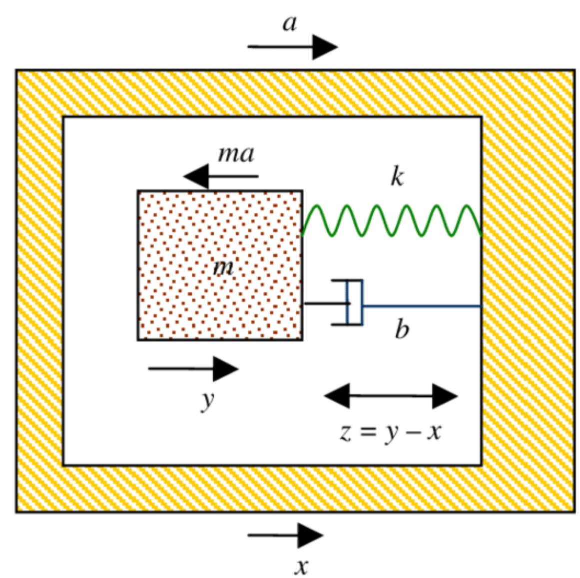
Amerini, Irene et al. "Robust smartphone fingerprint by mixing device sensors features for mobile strong authentication." *Media Watermarking, Security, and Forensics* (2016).

How does the spring stiffness affect the IMU?

How does the damping affect the IMU?

How would you design a 3D accelerometer

$$C = \frac{\varepsilon A}{d}$$



Krishnan, Girish et al. "Micromachined High-Resolution Accelerometers." *Journal of the Indian Institute of Science* 87 (2007): 333-360.

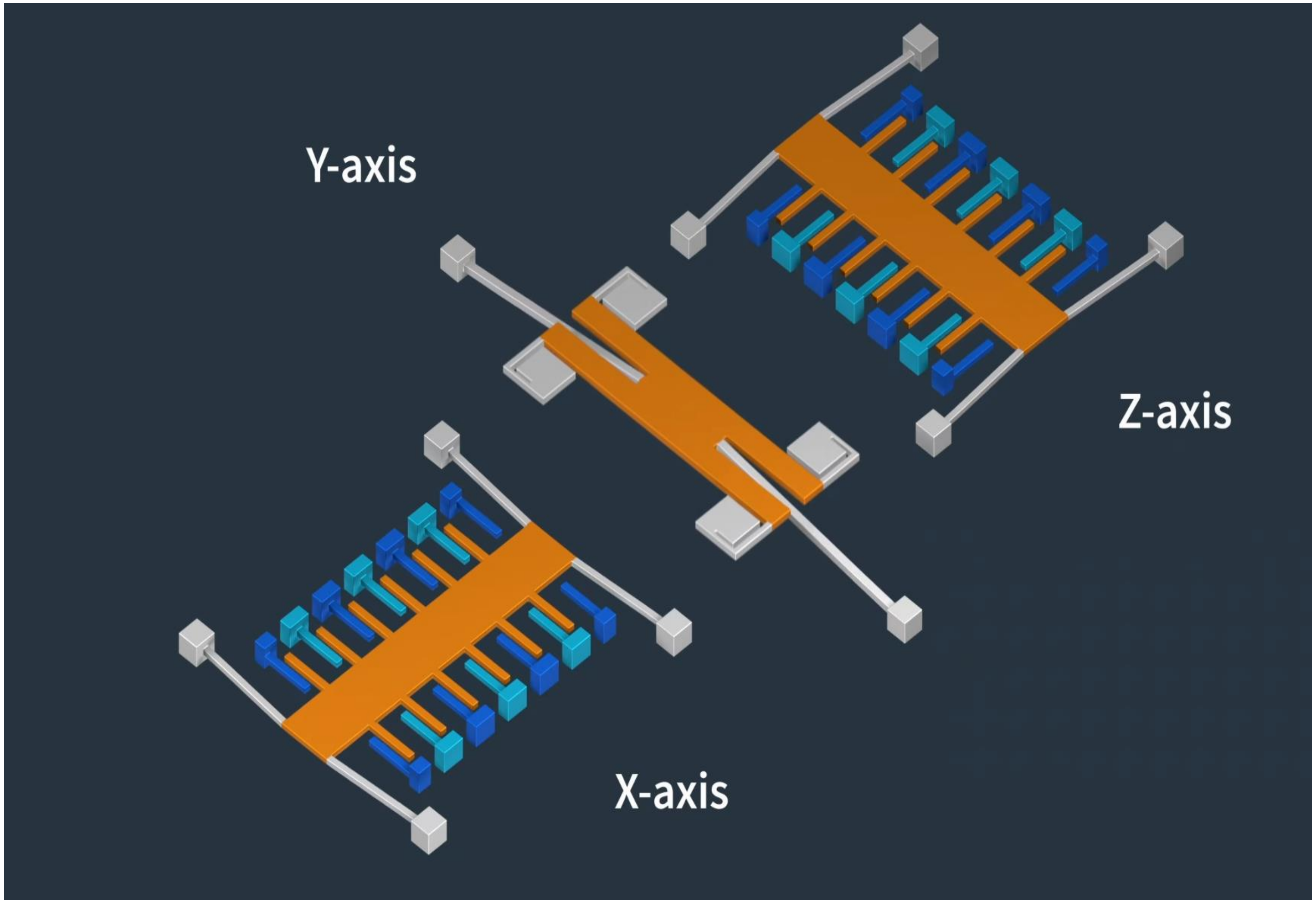
spring stiffness – k - **Sensitivity**: The stiffness of the spring affects the sensitivity of the IMU. A stiffer spring (k is large) will result in less displacement for a given acceleration, which can reduce the sensitivity of the accelerometer. Conversely, a less stiff spring (k is small) will allow more displacement, increasing sensitivity.

Dynamic Range: Stiffer springs can handle higher accelerations without significant displacement, thus increasing the dynamic range. However, if the spring is too stiff, the IMU may not be sensitive enough to detect small accelerations.

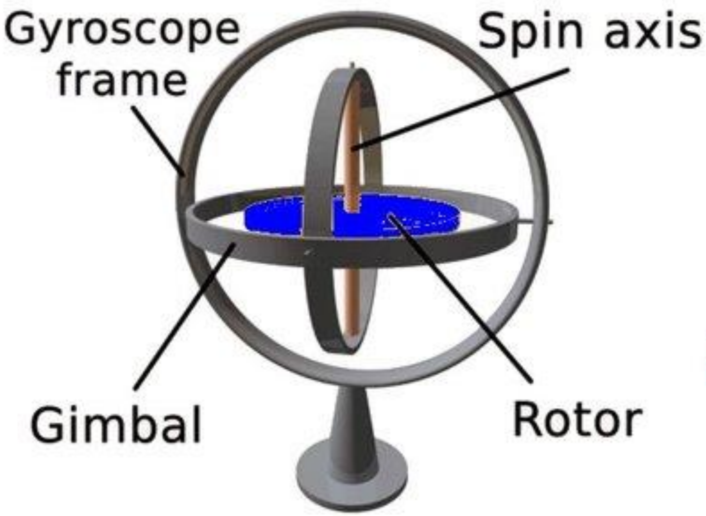
Natural Frequency: The natural frequency of the system is given by $\omega n=\sqrt{k}/m$, where m is the mass. Higher spring stiffness increases the natural frequency. This affects how the system responds to dynamic inputs and its ability to filter out high-frequency noise

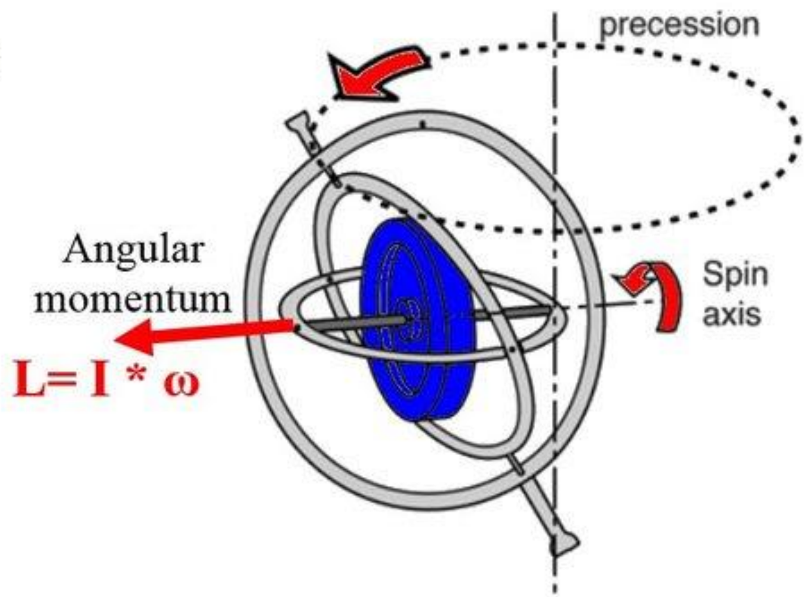
Hooke's law states that F = kx, x -the amount by which the free end of the spring was displaced from its "relaxed" position

Damping - Appropriate damping can improve the accuracy of the IMU by minimizing oscillations and noise. Under-damped systems can oscillate and produce inaccurate readings, while over-damped systems may respond too slowly to changes in acceleration.- good for fast motions


Y-axis
Z-axis
X-axis

IMU

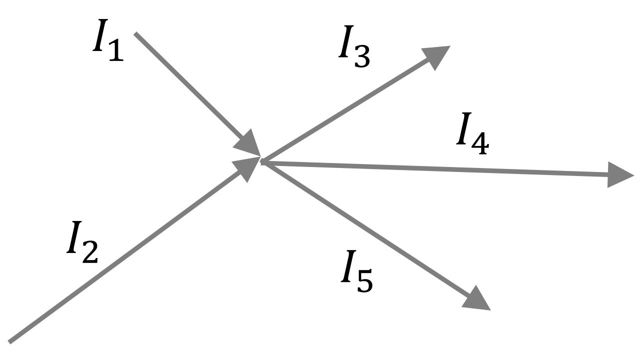




Hamza-Lup, Felix G.. "Kinesthetic Learning - Haptic User Interfaces for Gyroscopic Precession Simulation." *ArXiv* abs/1908.09082 (2019): n. pag.

Kirchhoff‘s current rule:

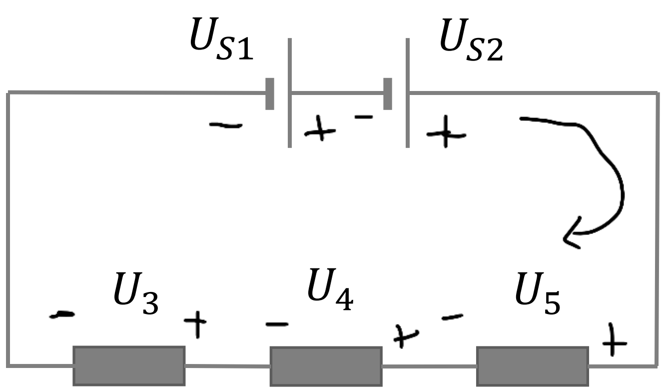
The sum of the currents flowing out of a circuit junction is equal to the sum of the currents flowing in.



$$I_1 + I_2 = I_3 + I_4 + I_5$$

2.Kirchhoff‘s voltage rule:

The directed sum of the voltages around a closed circuit loop is equal to zero.



$$U_{S1} + U_{S2} = U_3 + U_4 + U_5$$

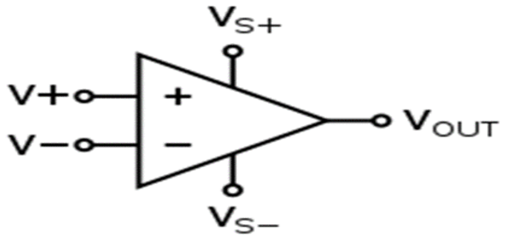
An operational amplifier (OpAmp) is a semiconductor-based circuit element which, in its ideal form, adjusts its output voltage so that the currents flowing in its input terminals is equal to zero, as is the diffrence in voltage between the terminals themselves.

The sensors in FMG systems generate small electrical signals corresponding to the muscle force or pressure applied. These signals are often too weak to be directly analyzed or used.

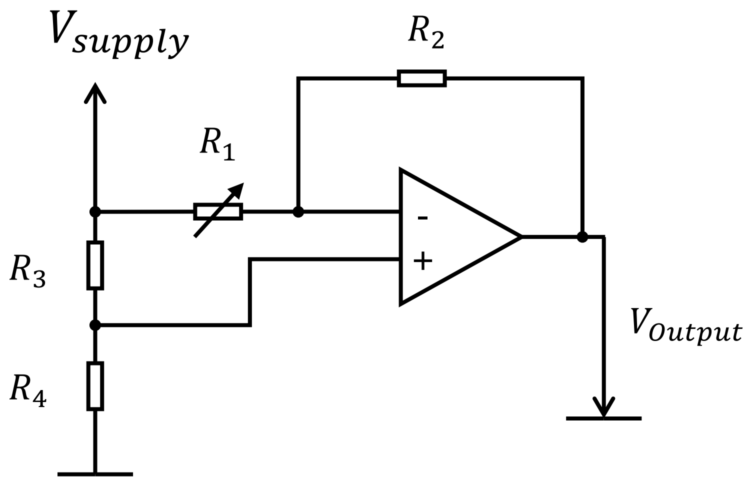
OpAmps - amplifiers to amplify the small differential signals from the sensors. This amplification makes the signals strong enough for further processing and analysis.

High Gain: The high gain provided by OpAmps ensures that even minute changes in muscle force are captured accurately.

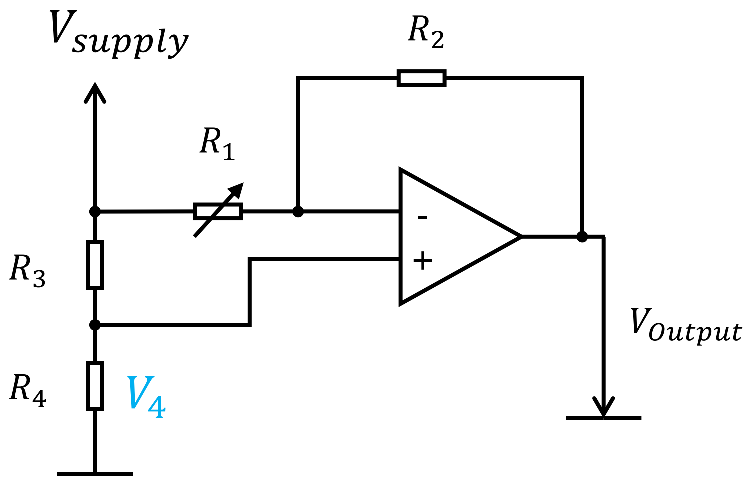
Also to reduce noise



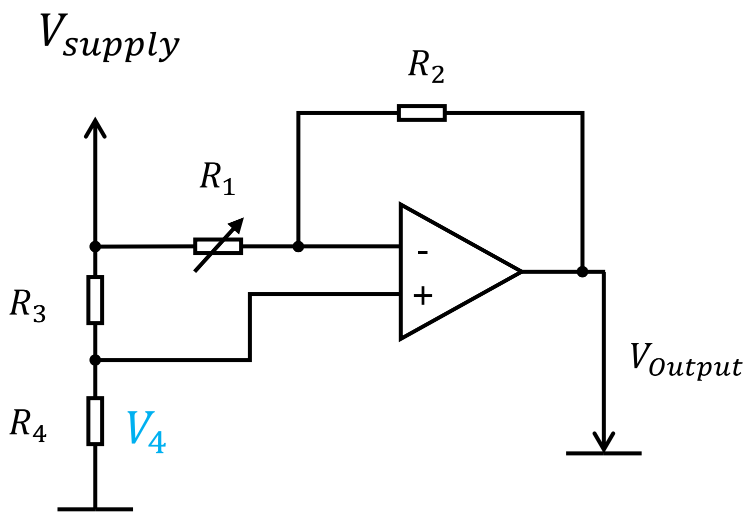
In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?

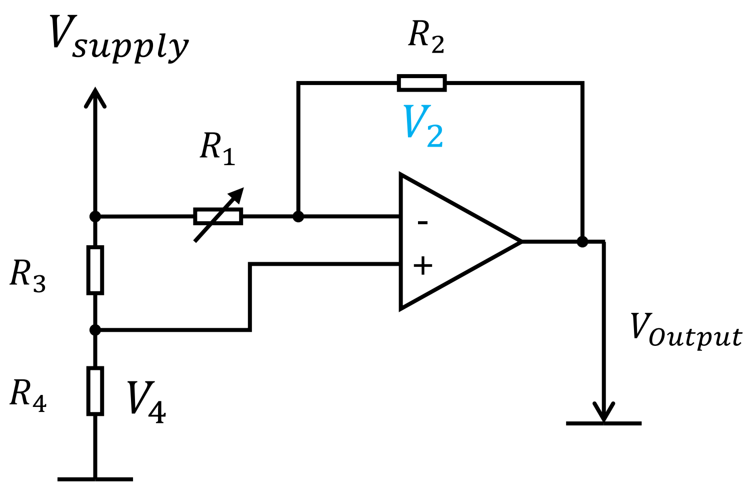


In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



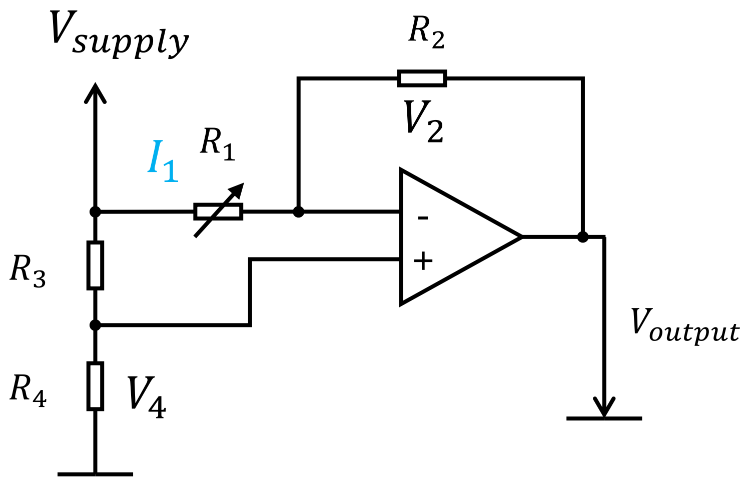
$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

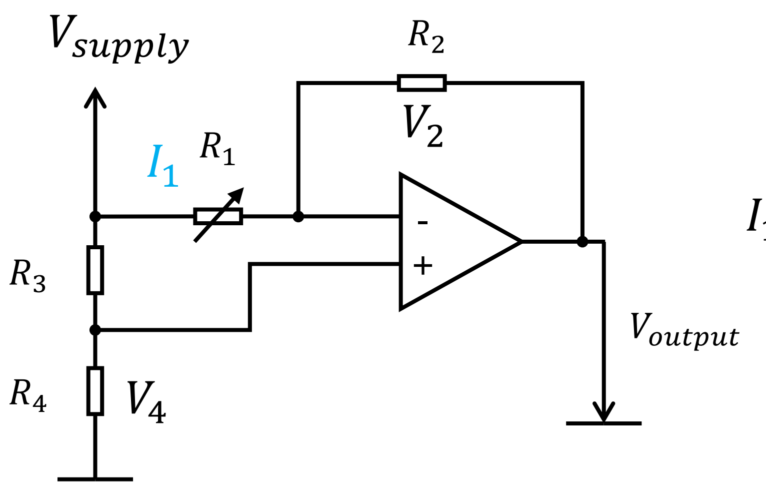
In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

$$V_2 = R_2 \cdot I_2$$

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?

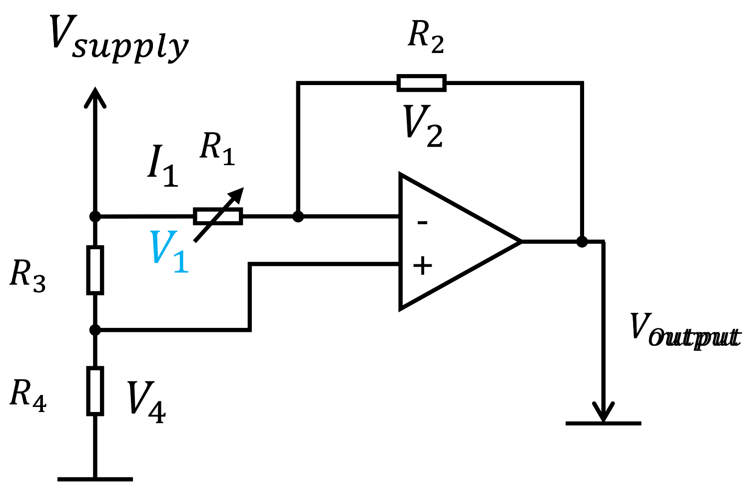


$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

$$V_2 = R_2 \cdot I_2$$

$$I_1 = \frac{V_1}{R_1} = \frac{R_3}{(R_3 + R_4) \cdot R_1} \cdot V_{supply}$$

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?

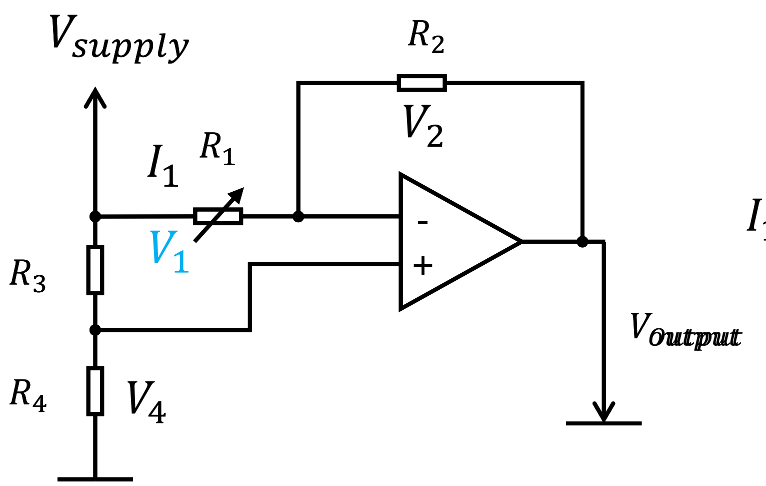


$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

$$V_2 = R_2 \cdot I_2$$

$$I_1 = \frac{V_1}{R_1} = \frac{R_3}{(R_3 + R_4) \cdot R_1} \cdot V_{supply}$$

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?

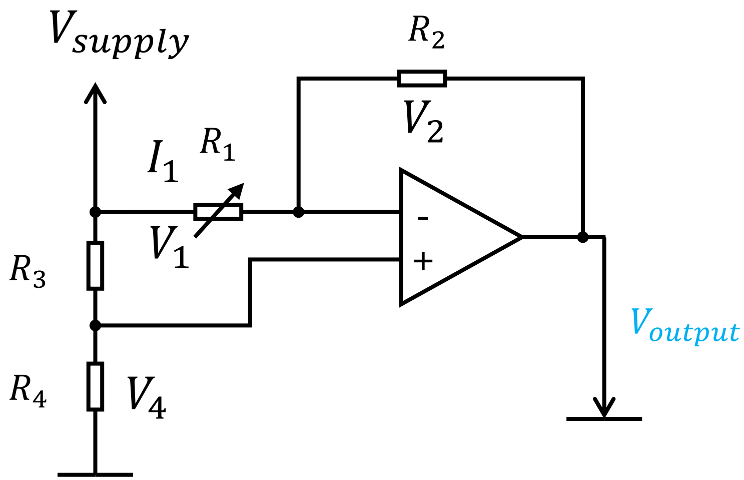


$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

$$V_2 = R_2 \cdot I_2$$

$$I_1 = \frac{V_1}{R_1} = \frac{R_3}{(R_3 + R_4) \cdot R_1} \cdot V_{supply}$$

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

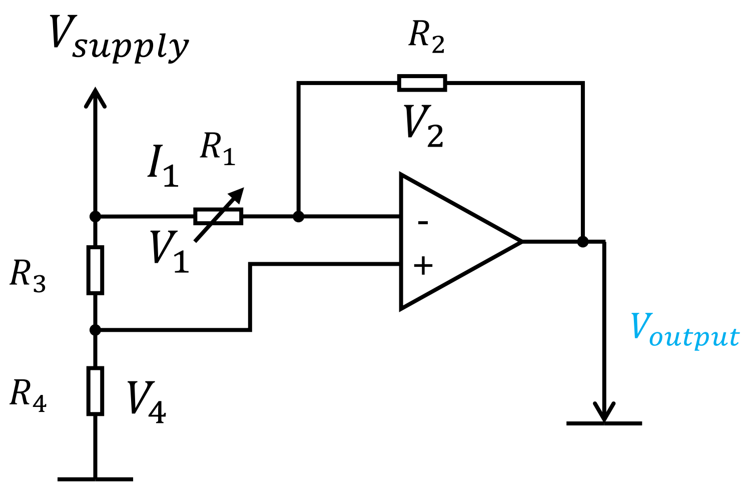
$$V_2 = R_2 \cdot I_2$$

$$I_1 = \frac{V_1}{R_1} = \frac{R_3}{(R_3 + R_4) \cdot R_1} \cdot V_{supply}$$

$$V_1 = V_3 = \frac{R_3}{R_3 + R_4} \cdot V_{supply}$$

FMG

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



$$V_4 = \frac{V_{supply}}{R_3 + R_4} \cdot R_4$$

$$V_2 = R_2 \cdot I_2$$

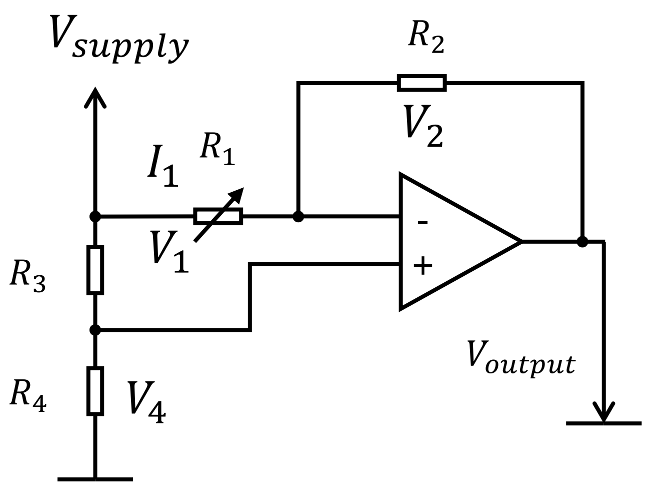
$$I_1 = \frac{V_1}{R_1} = \frac{R_3}{(R_3 + R_4) \cdot R_1} \cdot V_{supply}$$

$$V_1 = V_3 = \frac{R_3}{R_3 + R_4} \cdot V_{supply}$$

$$V_{output} = V_4 - V_2$$

$$= V_{supply} \cdot \frac{R_2}{R_3 + R_4} - V_{supply} \cdot \frac{R_2 \cdot R_3}{(R_3 + R_4) \cdot R_1}$$

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



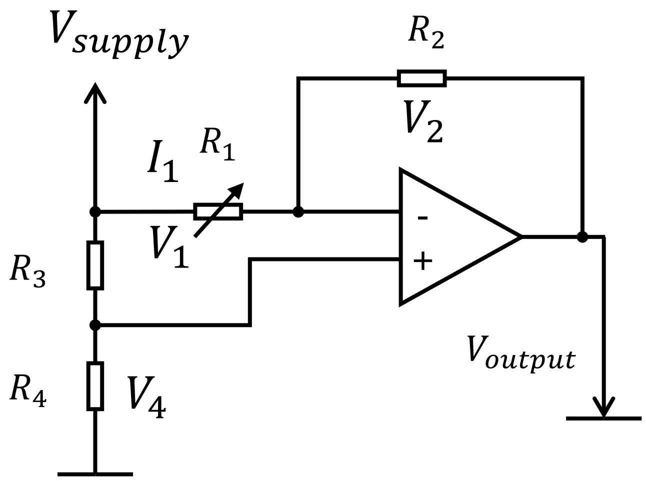
$$V_{output} = V_{supply} \cdot \left(\frac{R_2}{R_3 + R_4} + \frac{R_2 \cdot R_3}{R_1 \cdot (R_3 + R_4)} \right)$$

$$with\ R_1 = R + \alpha \cdot d$$

$$and\ R_2 = R_3 = R_4 = R$$

FMG

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



$$V_{output} = V_{supply} \cdot \left(\frac{R_2}{R_3 + R_4} + \frac{R_2 \cdot R_3}{R_1 \cdot (R_3 + R_4)} \right)$$

$$with\ R_1 = R + \alpha \cdot d$$

$$and\ R_2 = R_3 = R_4 = R$$

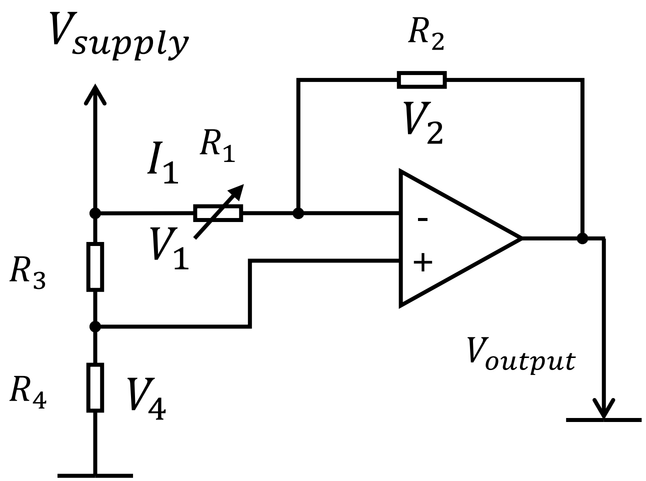
$$= V_{supply} \left(\frac{R}{2 \cdot R} - \frac{R^2}{2 \cdot R \cdot (R + \alpha \cdot d)} \right)$$

$$= V_{supply} \left(\frac{R^2 + R \cdot \alpha \cdot d - R^2}{2 \cdot R \cdot (R + \alpha \cdot d)} \right)$$

$$= V_{supply} \left(\frac{\alpha \cdot d}{2 \cdot (R + \alpha \cdot d)} \right)$$

FMG

In this exercise, we‘re going to look into Force Sensitive Resistor (FSR) amplification circuitry and mounting options. Consider the following circuit, where R_1 is a force sensitive resistor which reacts to its own deformation (strain) d by changing its value according to $R_1 = R + \alpha d$. What is the output voltage as a function of the strain d (assuming $R_2 = R_3 = R_4 = R$)?



$$V_{output} = V_{supply} \cdot \left(\frac{R_2}{R_3 + R_4} + \frac{R_2 \cdot R_3}{R_1 \cdot (R_3 + R_4)} \right)$$

$$with\ R_1 = R + \alpha \cdot d$$

$$and\ R_2 = R_3 = R_4 = R$$

$$= V_{supply} \left(\frac{R}{2 \cdot R} - \frac{R^2}{2 \cdot R \cdot (R + \alpha \cdot d)} \right)$$

$$= V_{supply} \left(\frac{R^2 + R \cdot \alpha \cdot d - R^2}{2 \cdot R \cdot (R + \alpha \cdot d)} \right)$$

$$= V_{supply} \left(\frac{\alpha \cdot d}{2 \cdot (R + \alpha \cdot d)} \right)$$

Imagine a set of FSR sensors in a bracelet. What would you imagine could be problematic when measuring a muscle bulging?

Rest

Muscle bulging

Imagine a set of FSR sensors in a bracelet. What would you imagine could be problematic when measuring a muscle bulging?

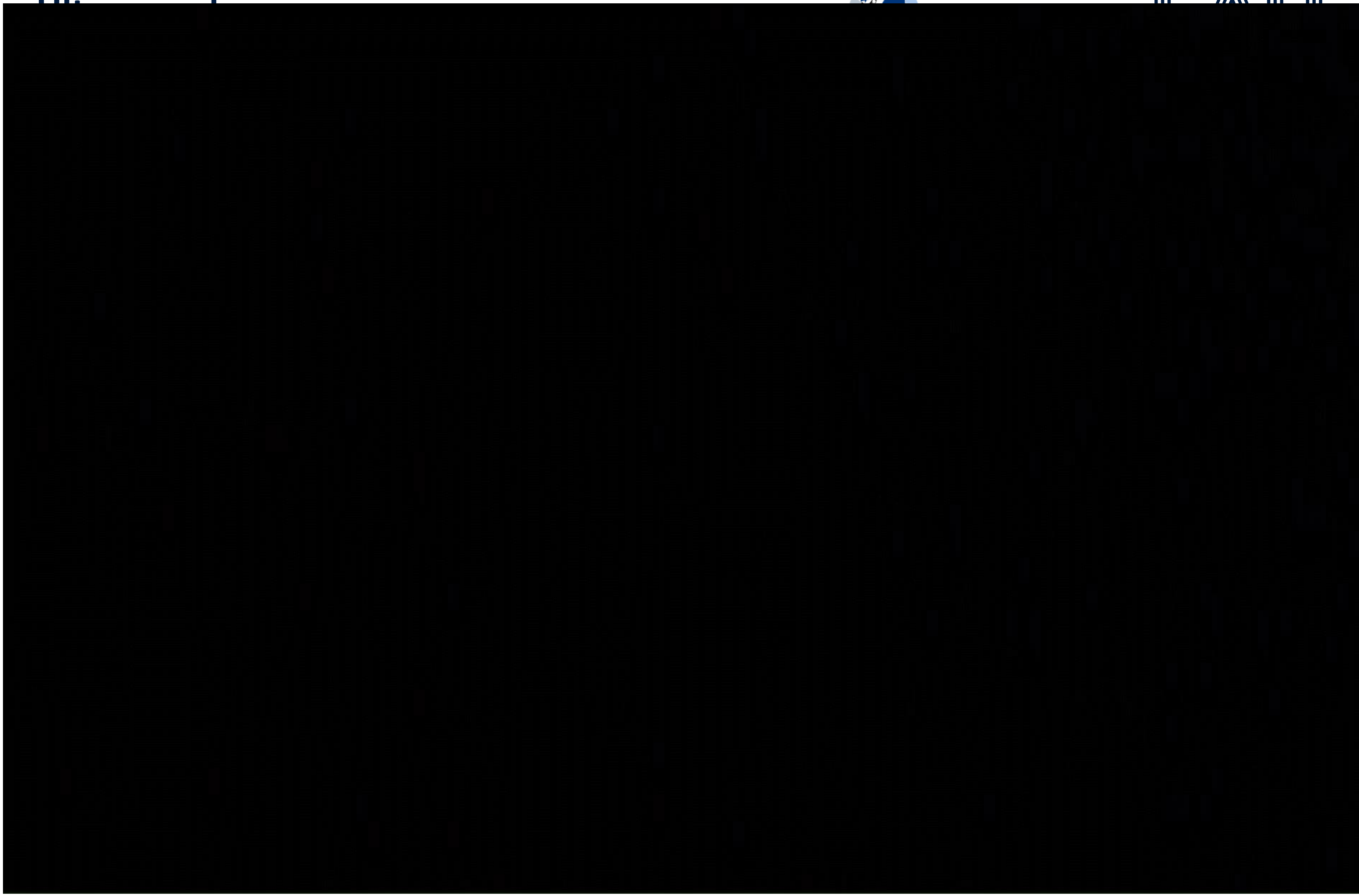
Solution:

Because the overall pressure, sumed over all area units, has to be zero in static conditions, one muscle bulging up on one side of the segment will cause pressure on the opposite side as well, leading to cross talk.

Independent Component Analysis could solve this problem. By applying ICA, the mixed signals from the sensors can be decomposed into independent components. This helps in isolating the true muscle bulging signals from the interfering signals.

Rest

Muscle bulging



Ultrasound

What are the benefits of Ultrasound with respect to EMG and FMG?

Benefits of Ultrasound in Prosthetics Compared to EMG

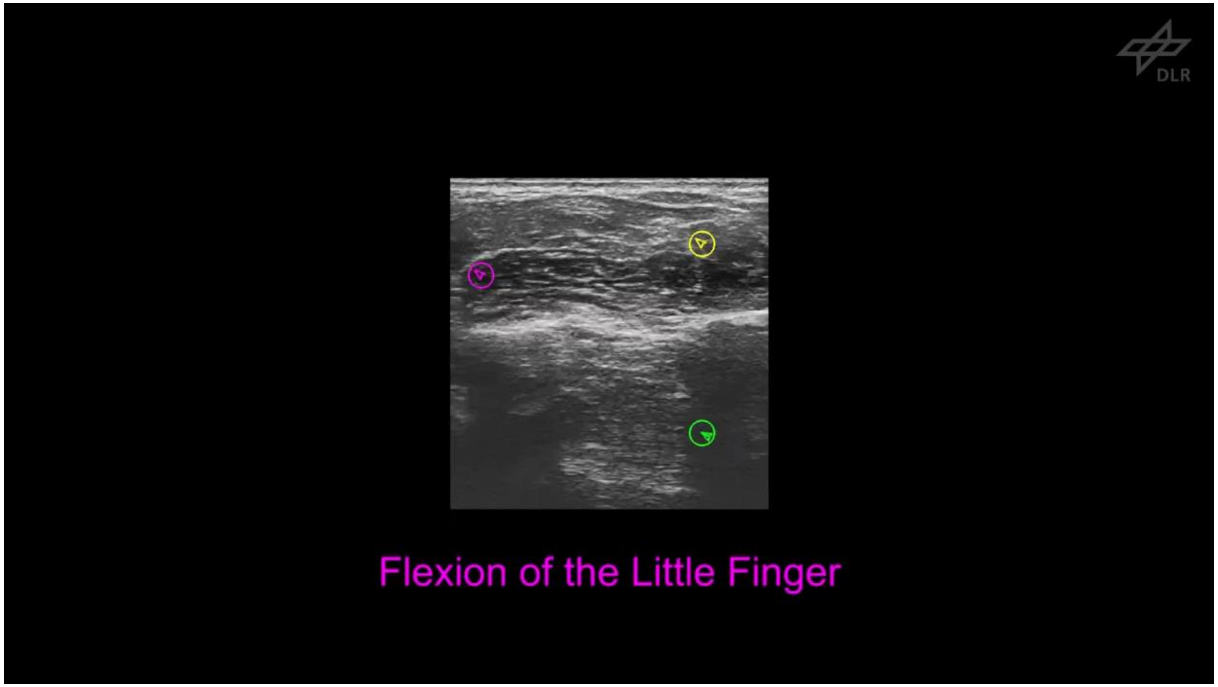
1. **Detailed Visualization**: Ultrasound provides real-time images of muscles and tendons, offering more precise information about muscle movements and conditions.
2. **Depth Information**: Captures data from deeper muscles that EMG surface electrodes cannot access.
3. **Non-Invasive**: Avoids the discomfort and potential risk of infection associated with needle electrodes used in some EMG applications.
4. **Functional Analysis**: Allows for the observation of muscle structure and function during movement, aiding in more accurate prosthetic control.

Benefits of Ultrasound in Prosthetics Compared to FMG

1. **Structural Insight**: Ultrasound gives clear images of muscle shape, size, and condition, which FMG cannot provide.
2. **Dynamic Assessment**: Can observe and assess muscle function in real-time, enhancing the accuracy of prosthetic control during different activities.
3. **Tissue Differentiation**: Effectively differentiates between various tissue types (muscle, tendon, fat), providing more comprehensive data than FMG, which only measures surface pressure changes.
4. **Precise Localization**: Ultrasound can precisely localize the source of muscle movements, improving the targeting and effectiveness of prosthetic control mechanisms.

Ultrasound

What are the benefits of Ultrasound with respect to EMG and FMG?



Friedrich-Alexander University
Erlangen-Nuremberg

Thank you
for your attention