UNIVERSITÄT DES SAARLANDES

Intelligent Material Systems Laboratory

Smart DE Glove as assistancetools for digital production environments

Conceptual presentation and preliminary studies on the development of a smart materials based haptic and sensory glove

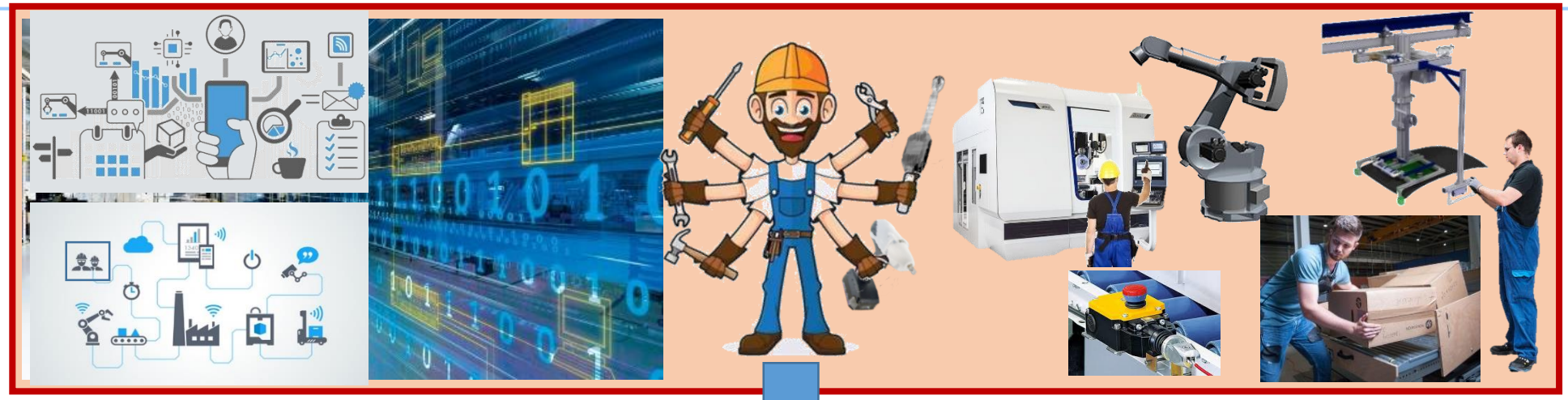
Sebastian Gratz-Kelly

Saarland University

PROMOTIONS-KOLLEG DIGITALISIERUNG DER PRODUKTION

ZeMA

Research objectives

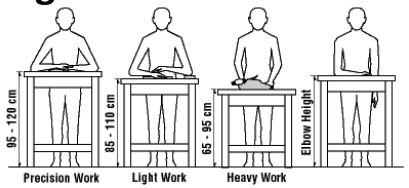


Intelligent haptic assistance tool

Quality control

Safety control

Ergonomics



Documentation

Haptic Feedback

Education

Communication

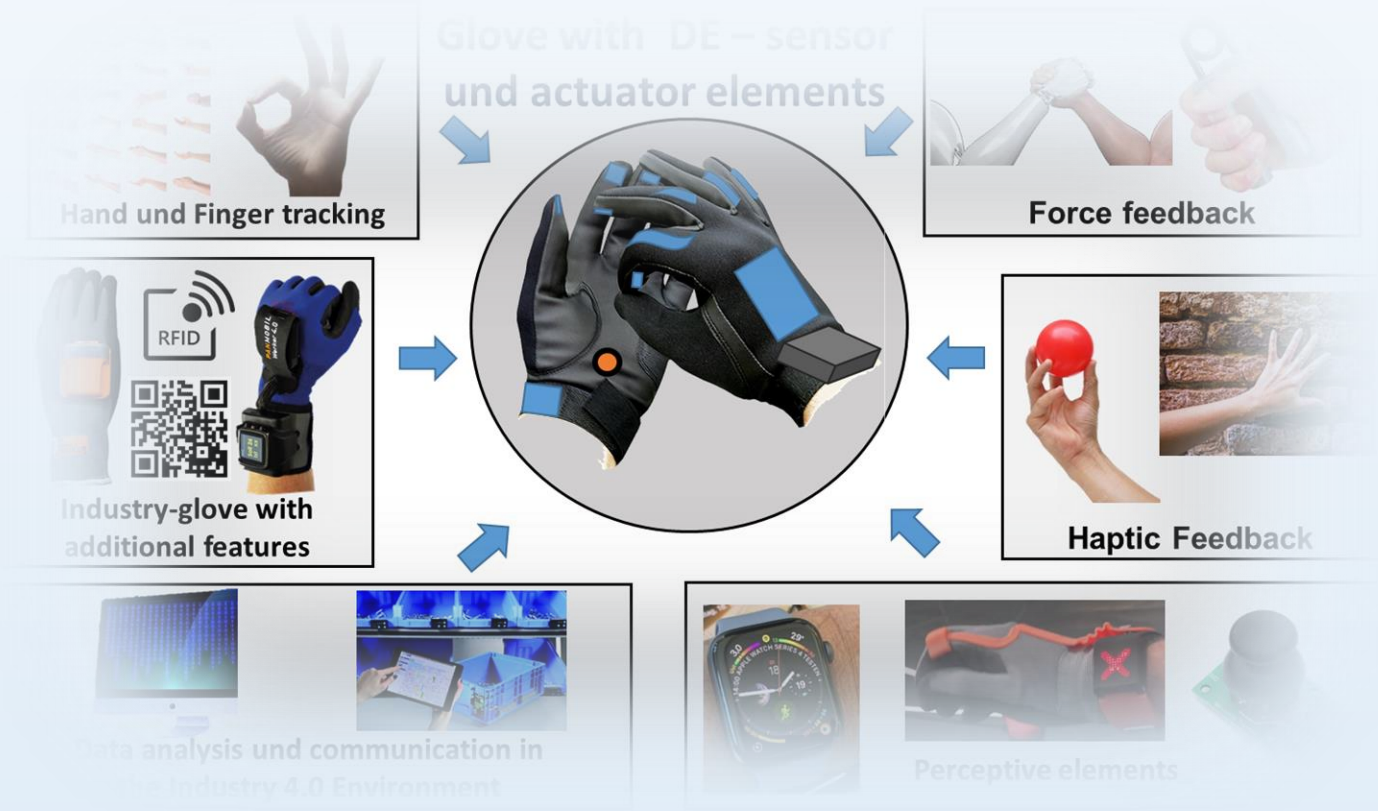
user input

Structure of the assistance tool
- sensor
- actuator
- electronic
- integration

Prototype assembly

Prototype validation

Summary and outlook



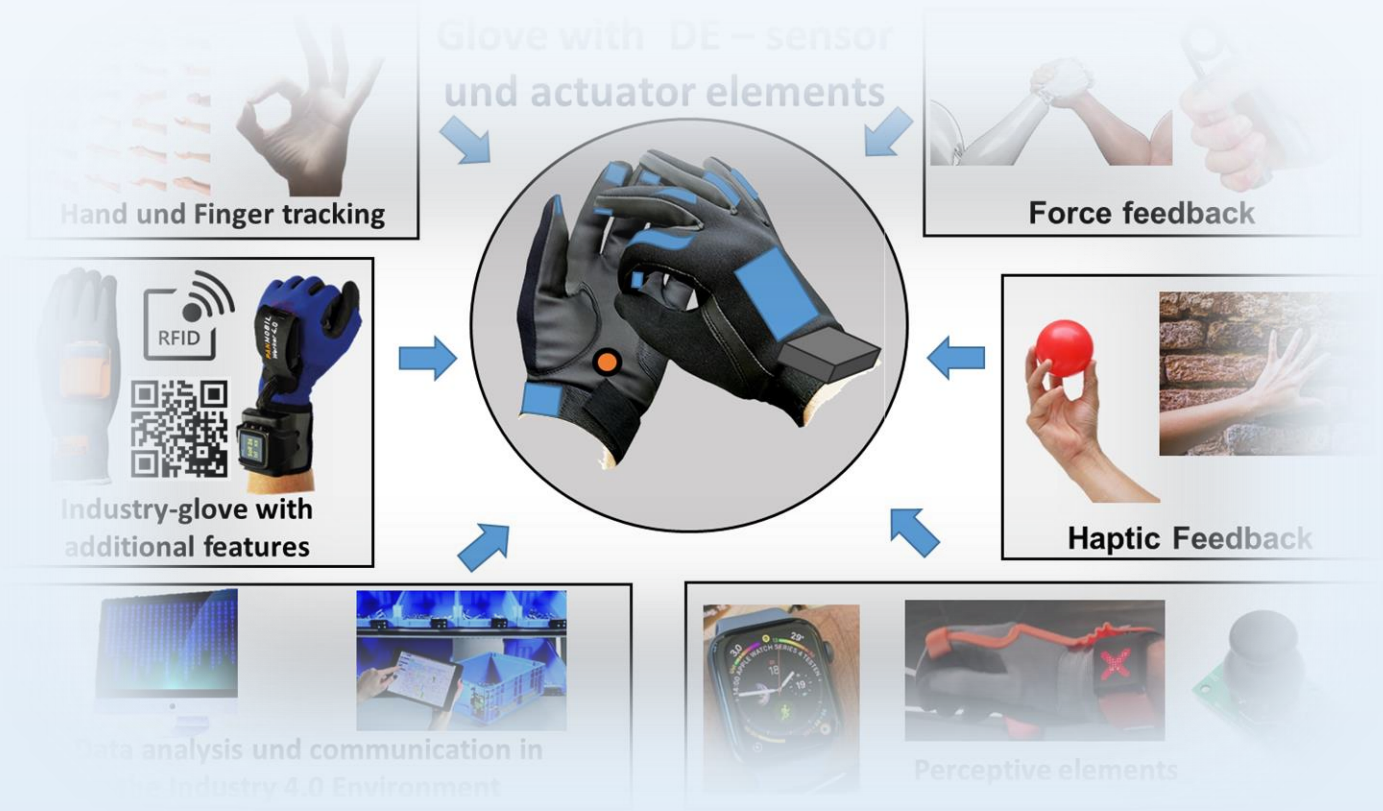
Structure of the assistance tool

- sensor
- actuator
- electronic
- integration

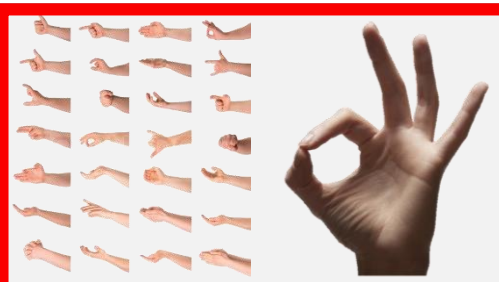
Prototype assembly

Prototype validation

Summary and outlook



Glove with DE – sensor und actuator elements

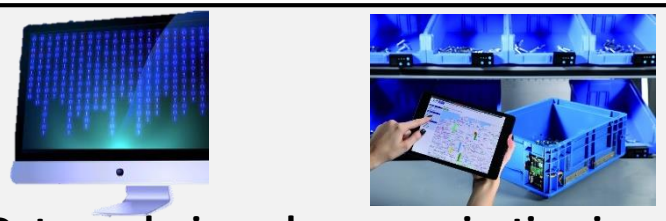


Hand und Finger tracking

Force feedback

Industry-glove with additional features

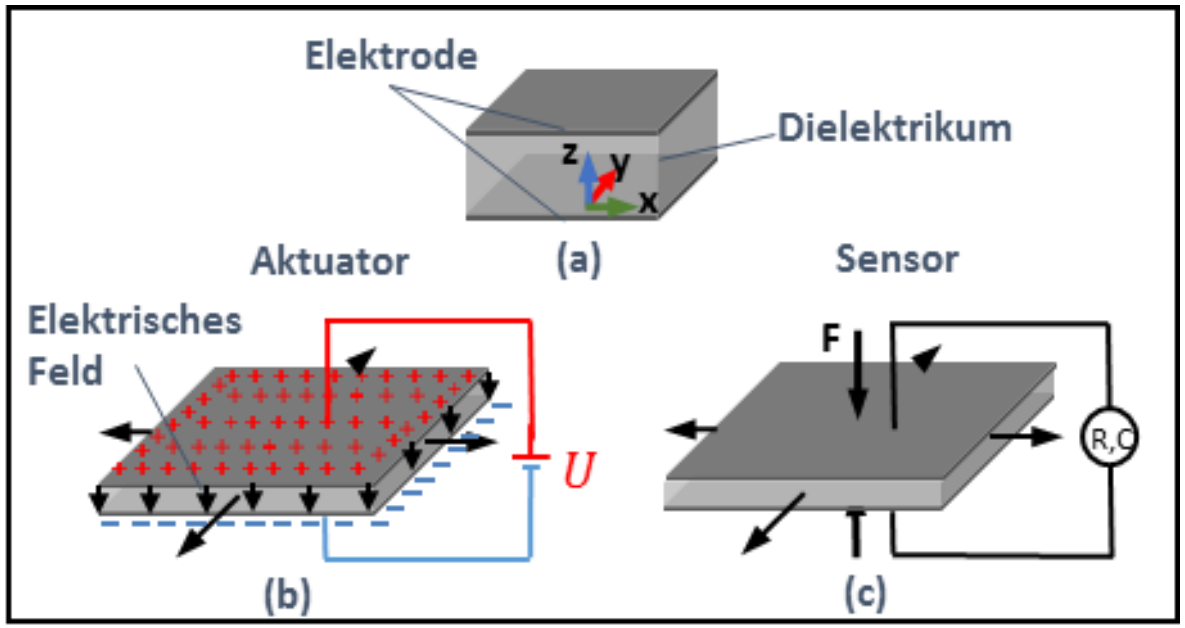
Haptic Feedback



Data analysis und communication in the Industry 4.0 Environment

Perceptive elements

DE as actuator and sensor



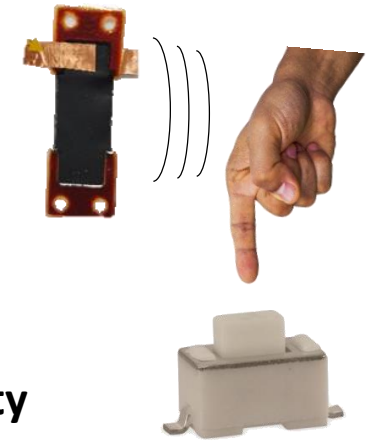
actuator

Vibration

Force pulse

Displacement

Increased rigidity



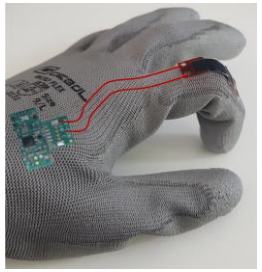
sensor

Force

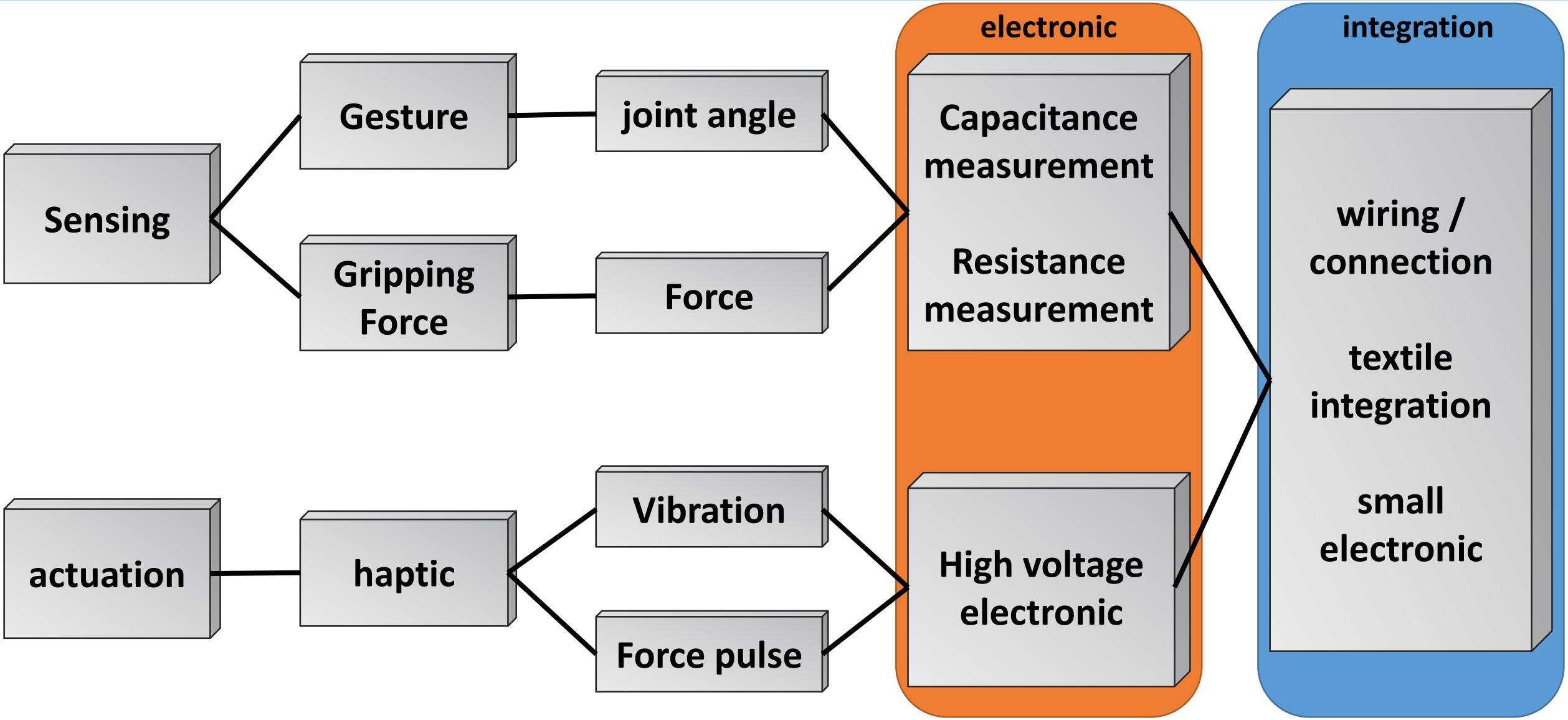
Pressure

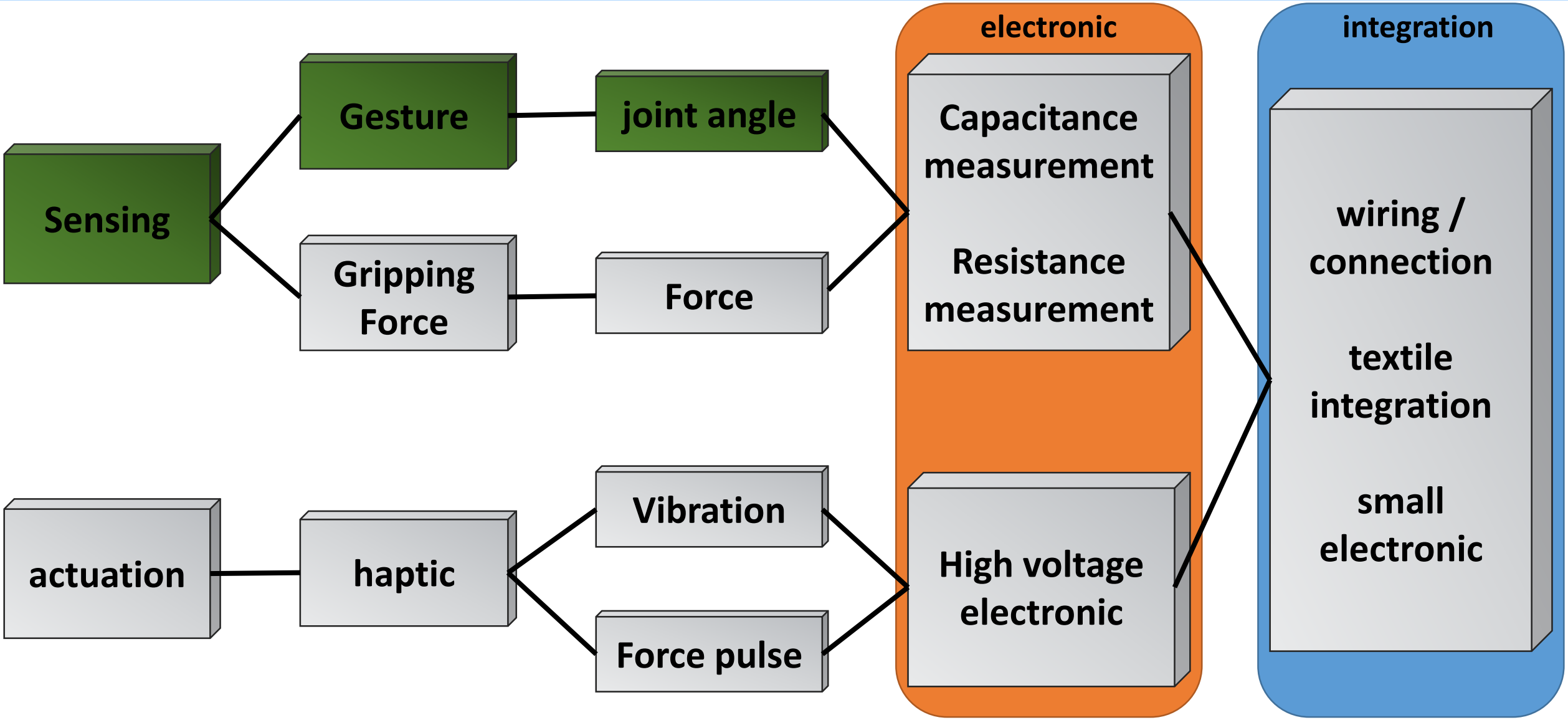
stretch

angle



http://solutions.parker.com/FlexSenseKit


Sensing
Gesture
Gripping Force
joint angle
Force
actuation
haptic
Vibration
Force pulse
electronic
Capacitance measurement
Resistance measurement
High voltage electronic
integration
wiring / connection
textile integration
small electronic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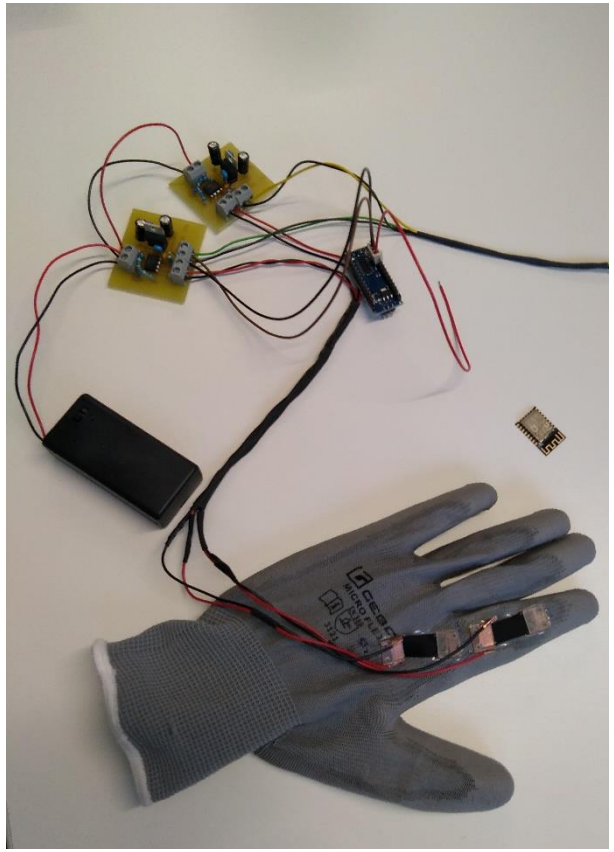
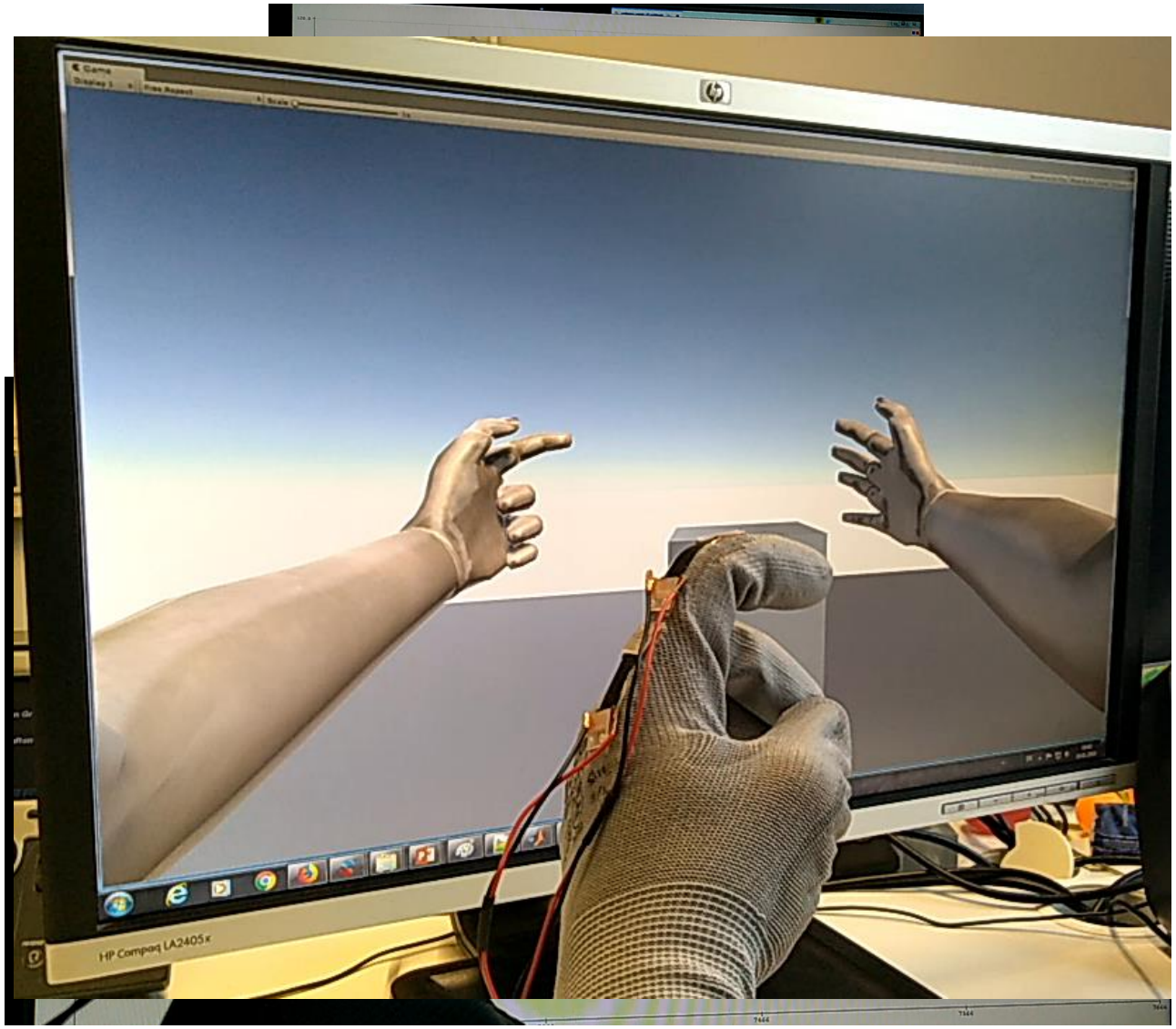
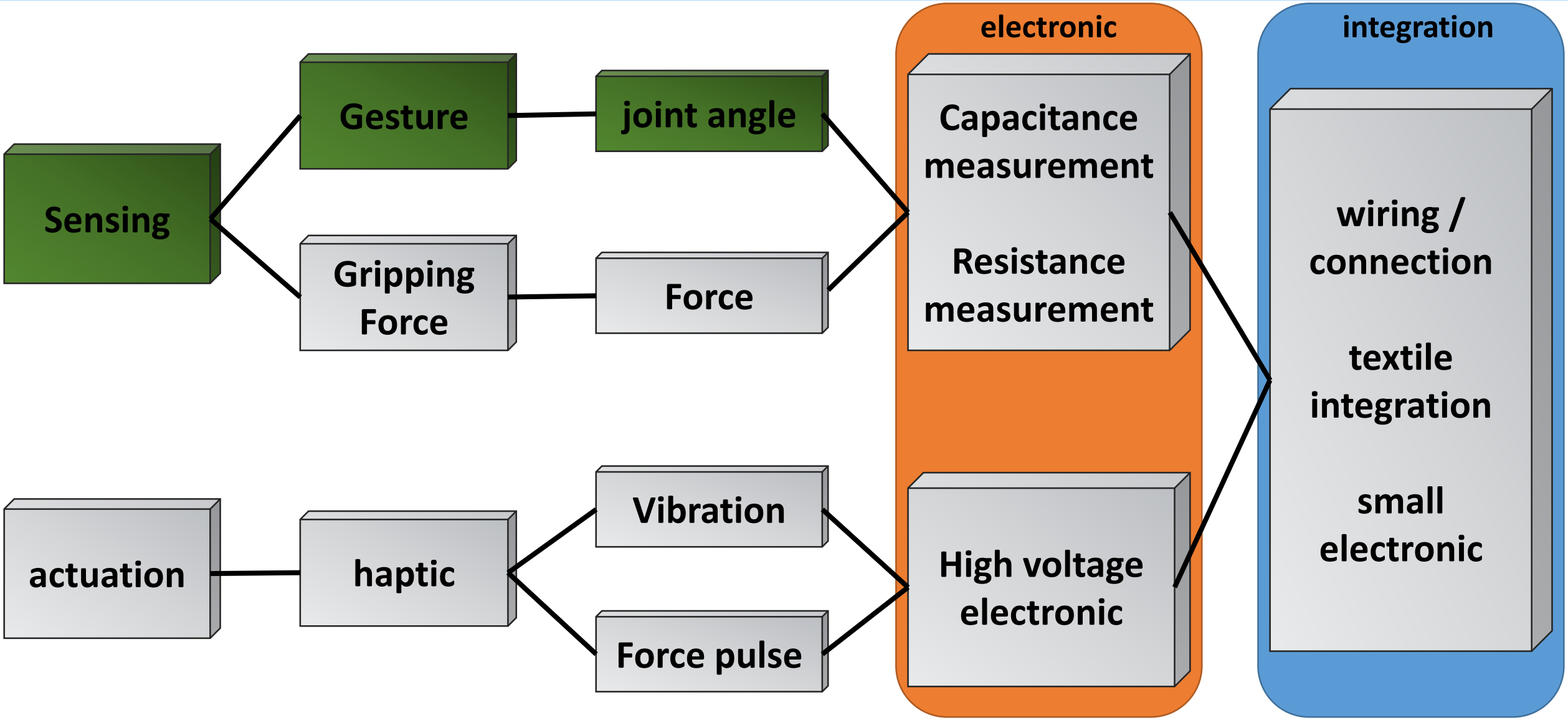
First Prototype test



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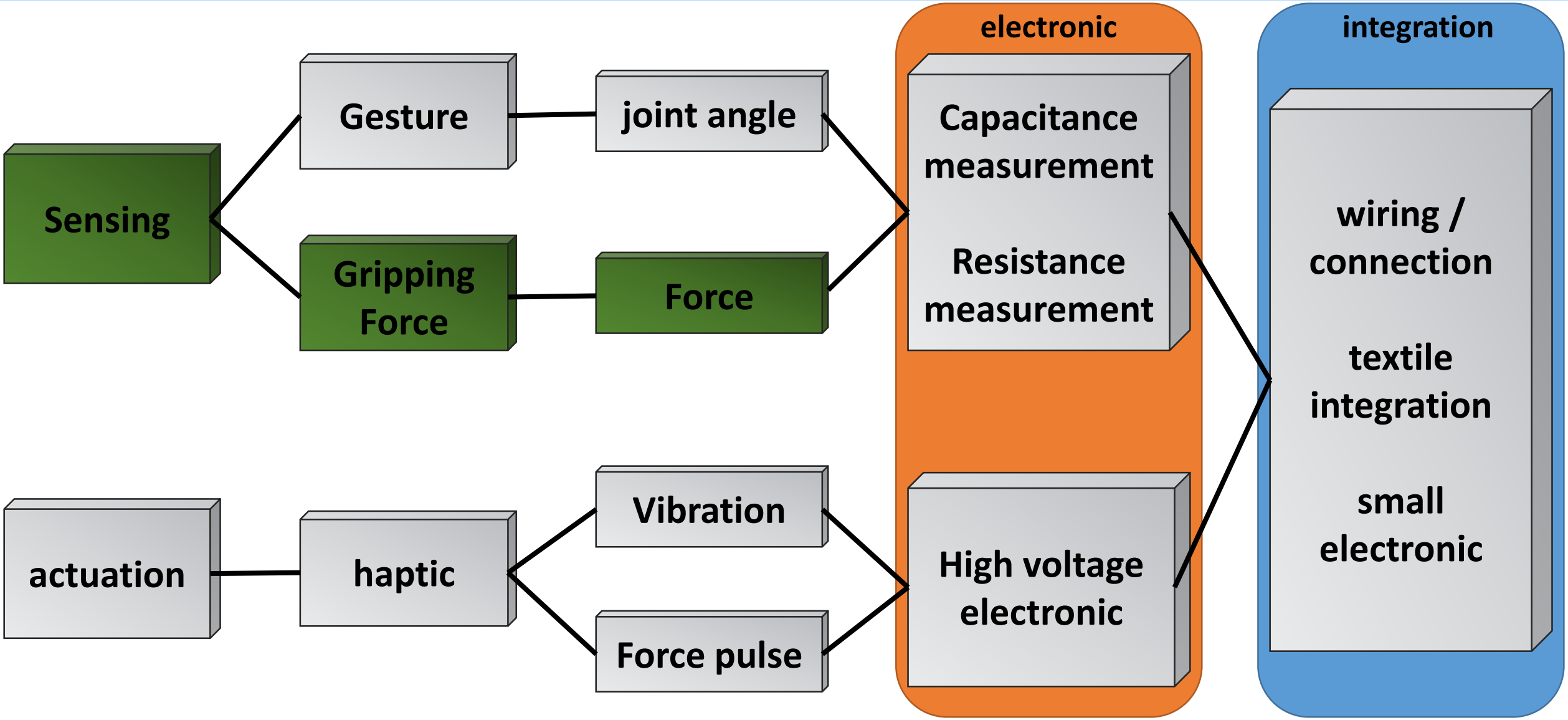
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Assembly Forces

pressing forces

tightening forces

Activation / safty

Tightening torque

Directional forces

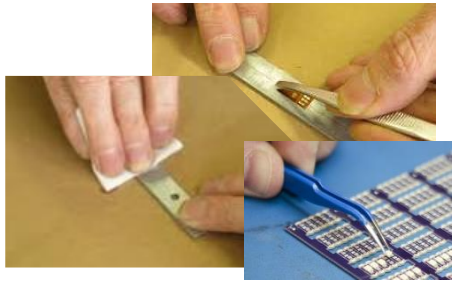
communication

low force

weight force

mounting force

Tool force

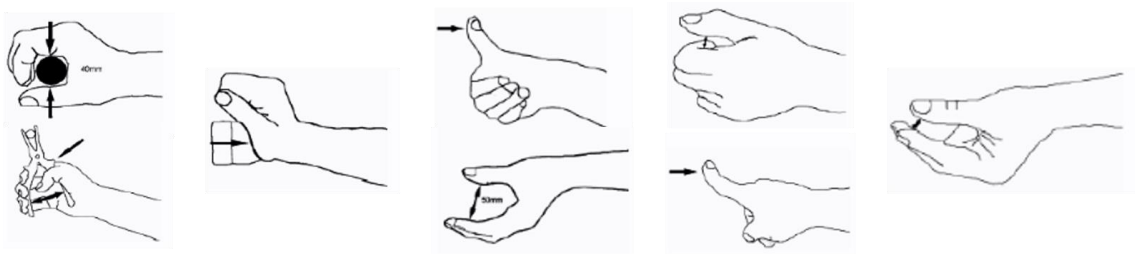


fine force

Component shape

Assembly Forces

Mainly used hand positions and corresponding maximum allowed forces



(a) (b) (c) (d) (e)

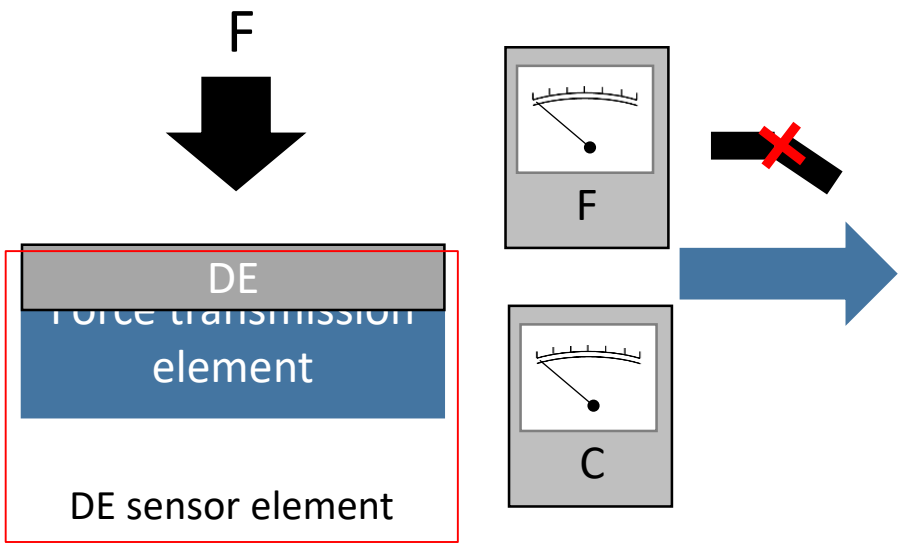
Grasp	Force (N)							
	fine			continue / often	"normal"			maximal
	0,50%	1%	2%	10%	33%	50%	66%	100%
(a) Span	0,9	1,8	3,6	18	60	90	120	180
(b) Palm push	0,825	1,65	3,3	16,5	55	82,5	110	165
(c) Thumb push	0,35	0,7	1,4	7	23,3	35	46,7	70
(d) Finger push/pinch	0,25	0,5	1	5	16,7	25	33,3	50
(e) Finger slide	0,05	0,1	0,2	1	3,3	5	6,7	10

For the different movements of the hand the forces to be measured vary from millinewton range to several hundred Newton

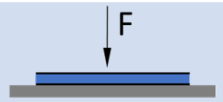
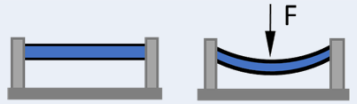
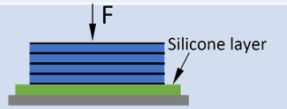
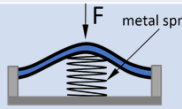
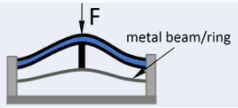
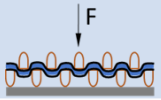
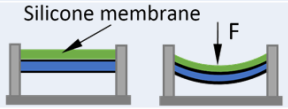
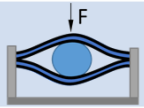
Different Sensor principle

Capacitor with variable geometry

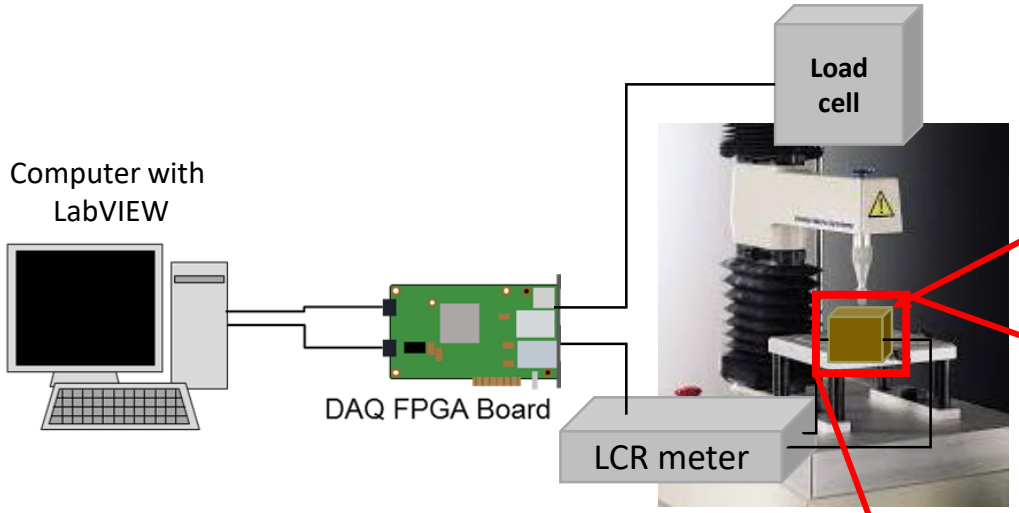
$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}$$



- low capacitance change
- only low force range measurable

Nr.	Geometry / measurement principle	Description
(a)		Single DE layer
(b)		Single DE layer clamped
(c)		Multiple DE layers with additional silicone layer
(d)		DE + flexible pre stretch element
(e)		DE + metal spring
(f)		DE + metal element
(g)		DE with structured Electrode
(h)		DE + silicone membrane
(i)		Double DE + inner pre stretch element

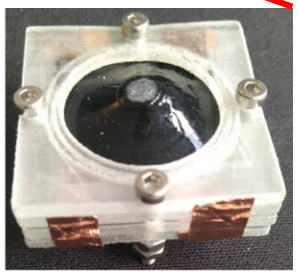
Characterization of the different sensor principles

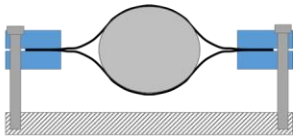


testing different sensor principles

Sensor probe

Sensor examples

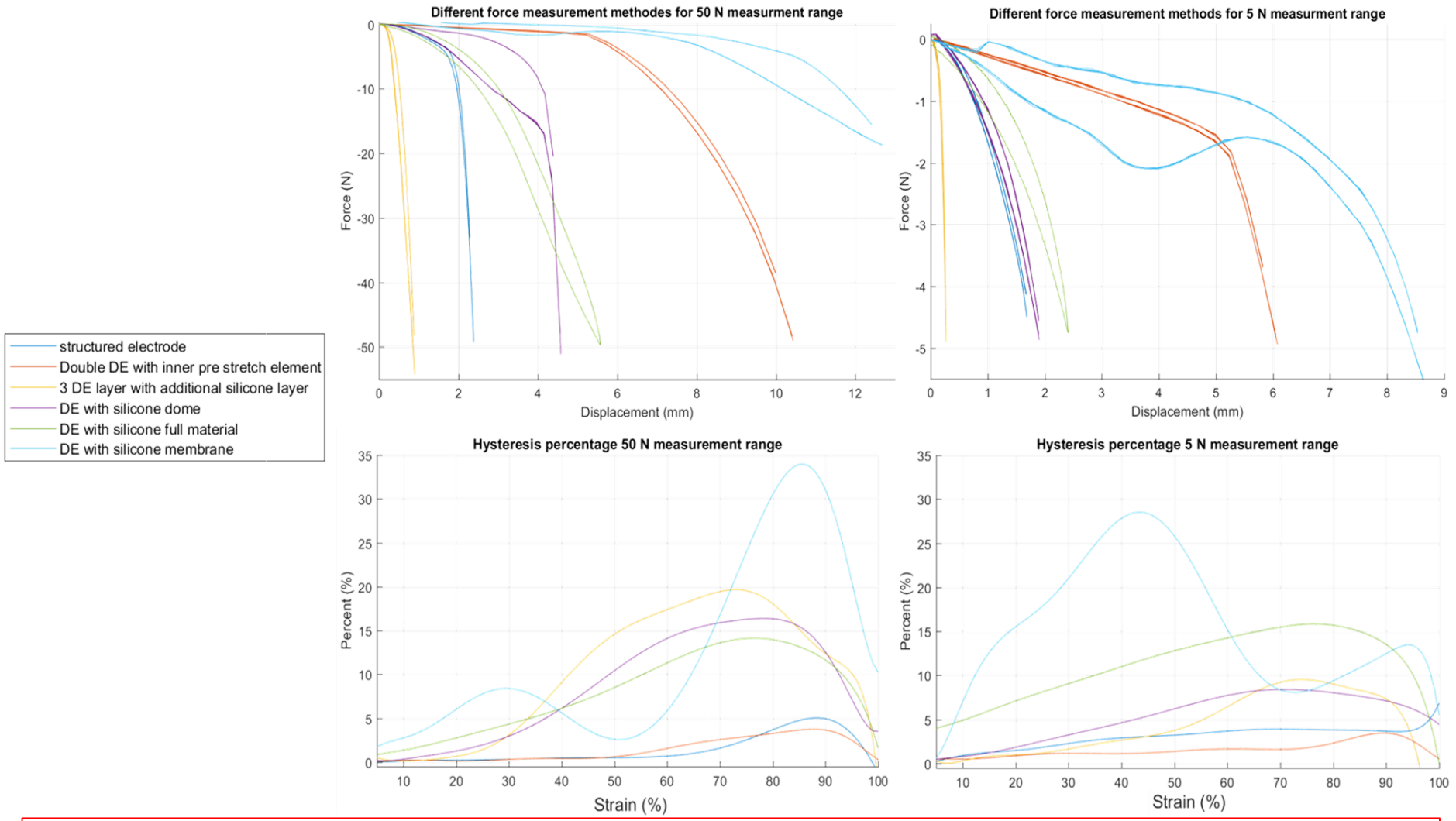




(a) (b)

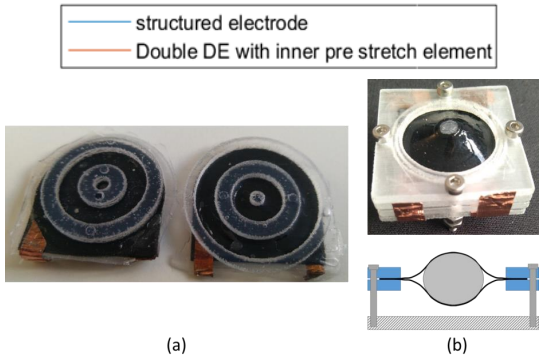
- capacitance measurement (LCR meter)
- force measurement (load cell)

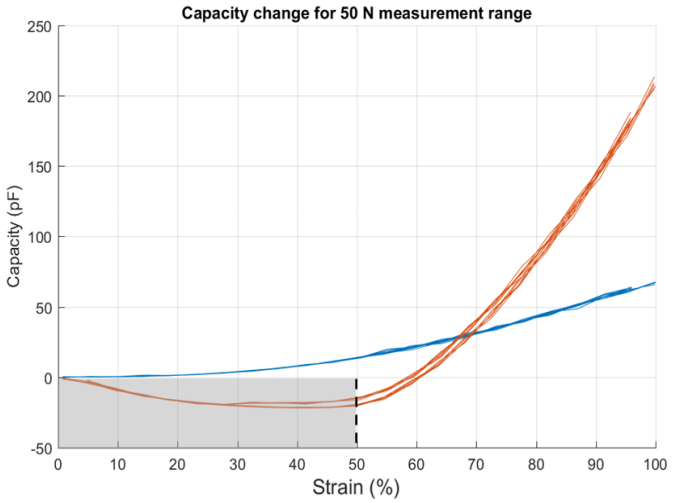
Comparison of different sensor principles

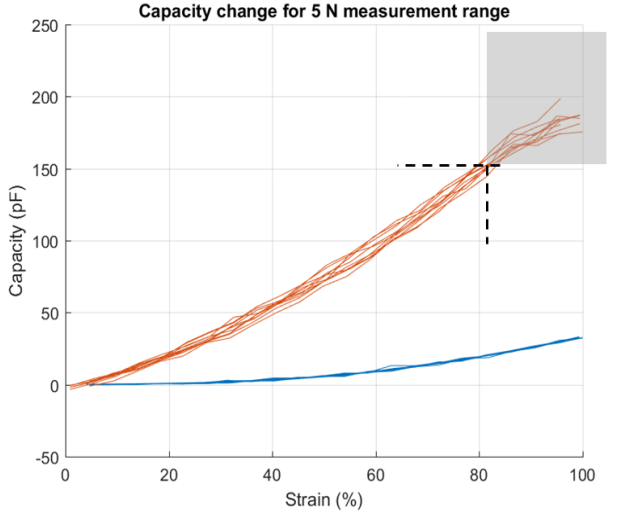


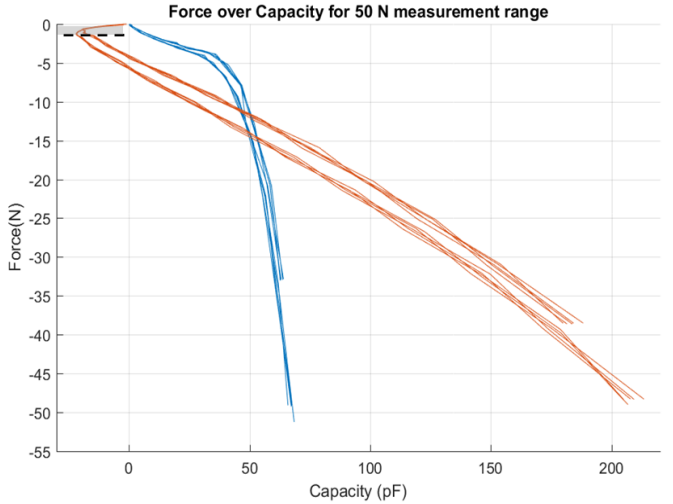
The different principles show hysteresis with different strength

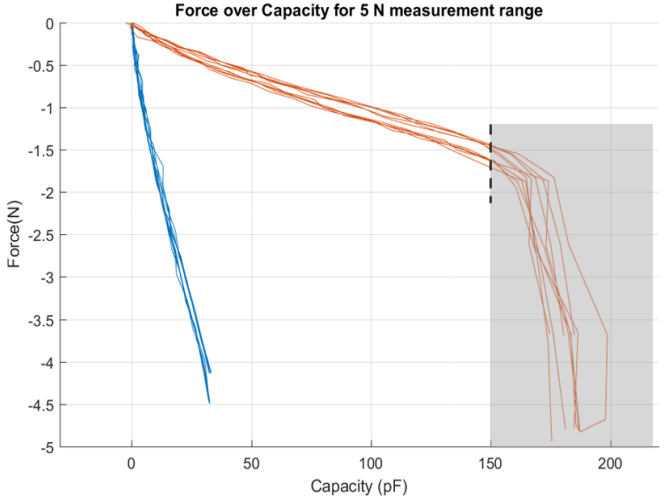
Capacity for the favorite sensor principle







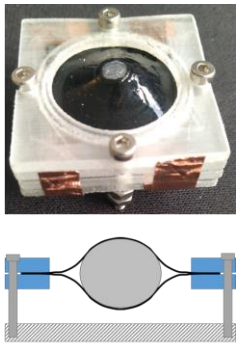




force and capacitance measurement

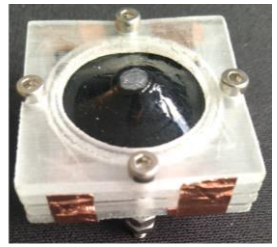
➡ force resolution and the needed capacitance resolution of the sensor element

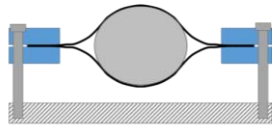
Measurement routine:
5 measurements for every force range
with 5 measurement cycles.



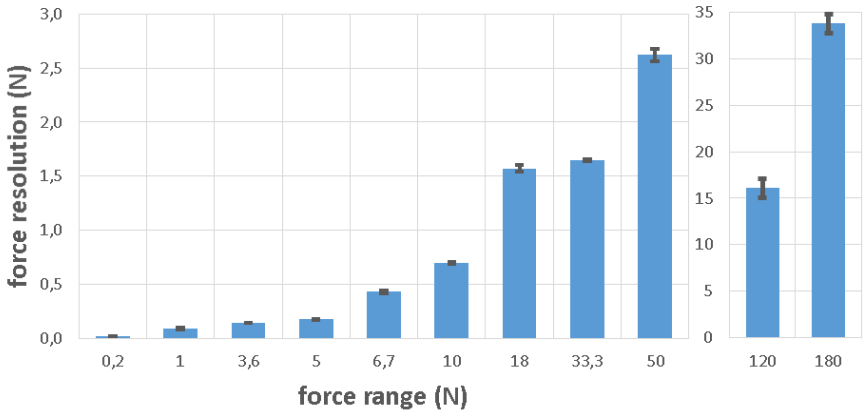
	structured DE		double DE		structured DE		double DE		structured DE		double DE		structured DE		double DE	
	3,6 N				18 N				120 N				180 N			
	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ
C min (pF)	0,185	0,106	1,256	0,138	0,415	0,063	2,779	0,291	0,769	0,427	5,826	0,169	2,536	0,861	7,006	1,092
F max (N)	0,144	0,002	0,133	0,011	1,573	0,031	1,274	0,005	16,084	0,025	6,539	0,037	33,778	0,199	12,087	0,233
	1 N				5 N				33,3 N				50 N			
	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ
C min (pF)	0,072	0,017	1,868	0,452	0,252	0,107	2,055	0,685	0,342	0,085	2,779	0,291	0,620	0,064	3,744	0,474
F max (N)	0,092	0,110	0,044	0,002	0,178	0,006	0,186	0,015	1,645	0,009	1,274	0,005	2,621	0,059	1,969	0,027
	0,2 N				1 N				6,7 N				10 N			
	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ	⌀	σ
C min (pF)	0,045	0,007	1,552	0,096	0,072	0,017	1,868	0,452	0,284	0,045	0,998	0,048	0,356	0,069	2,012	0,052
F max (N)	0,022	0,003	0,022	0,003	0,092	0,110	0,044	0,002	0,434	0,012	0,239	0,003	0,701	0,009	0,416	0,005

Statistic table of capacitance and force for different force range

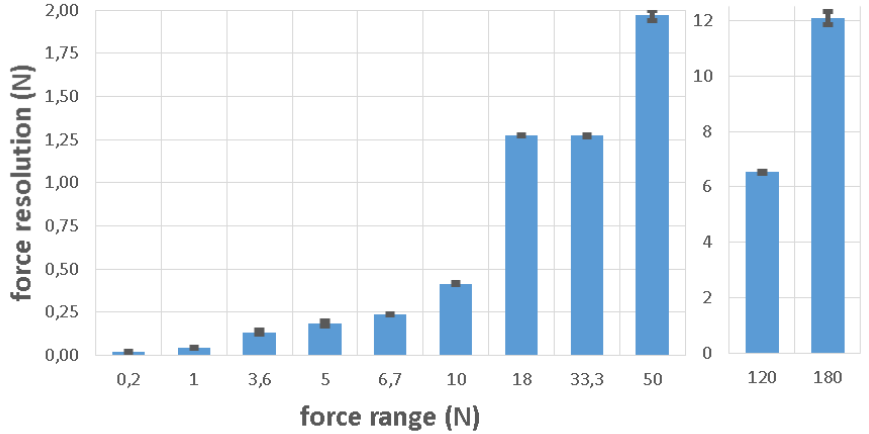




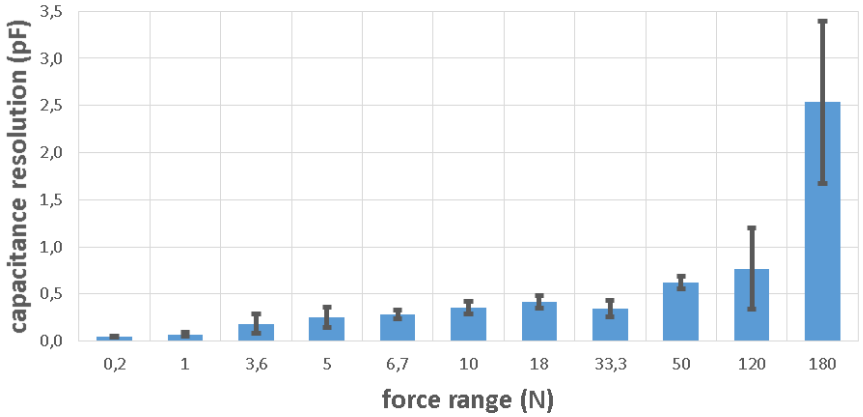
force resolution for the structured DE



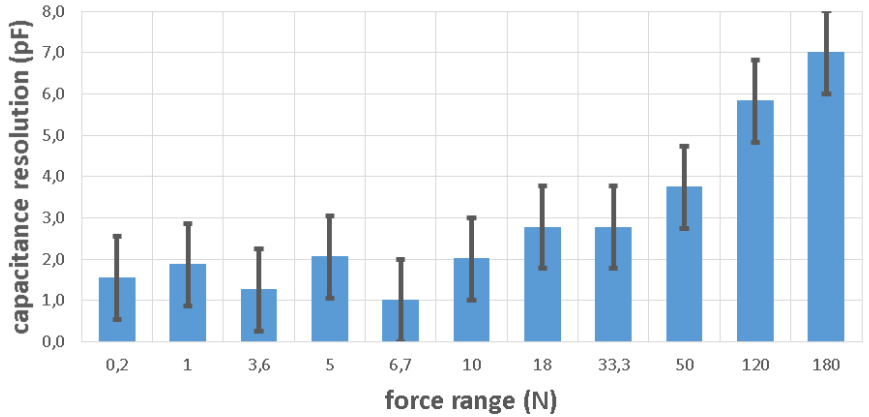
force resolution for the double DE

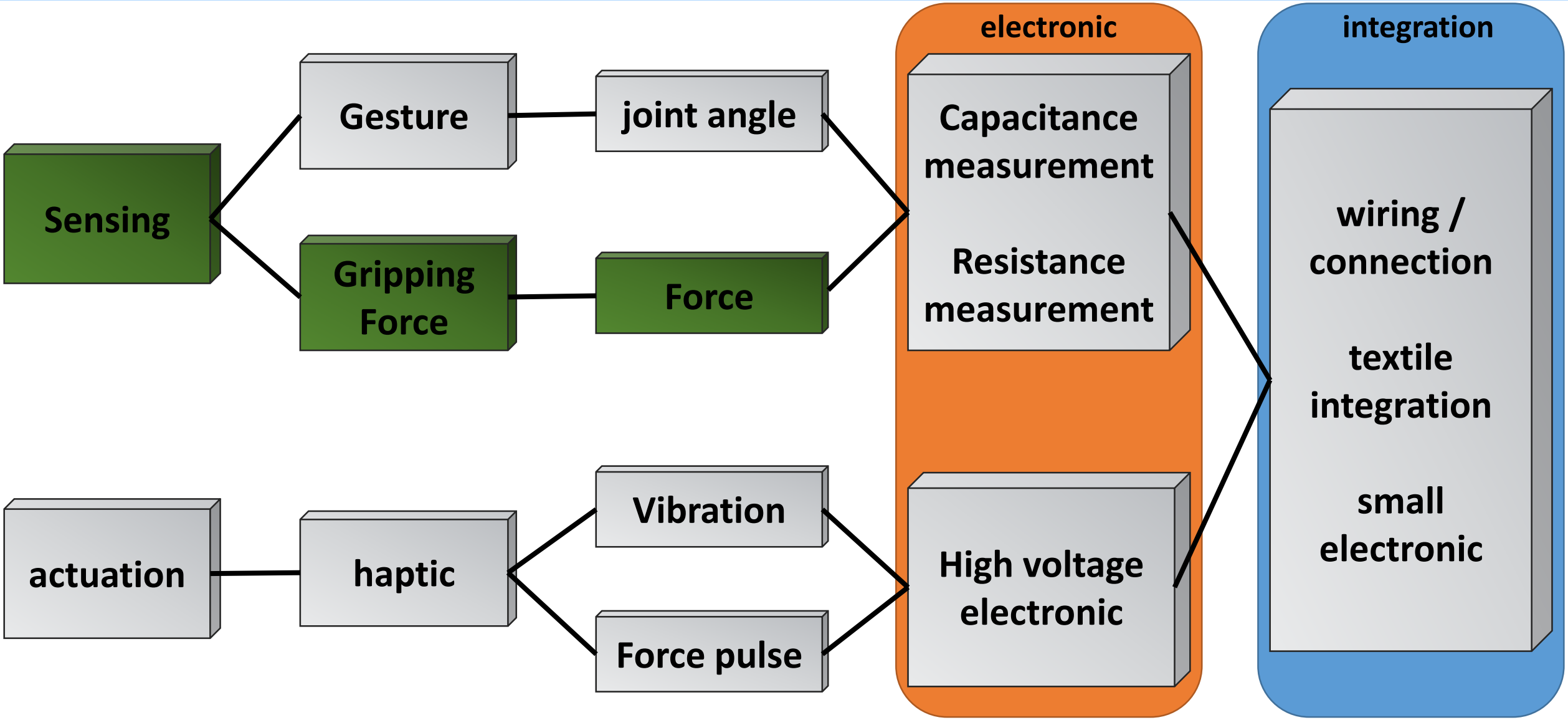


capacitace resolution for the structured DE



capacitace resolution for the double DE

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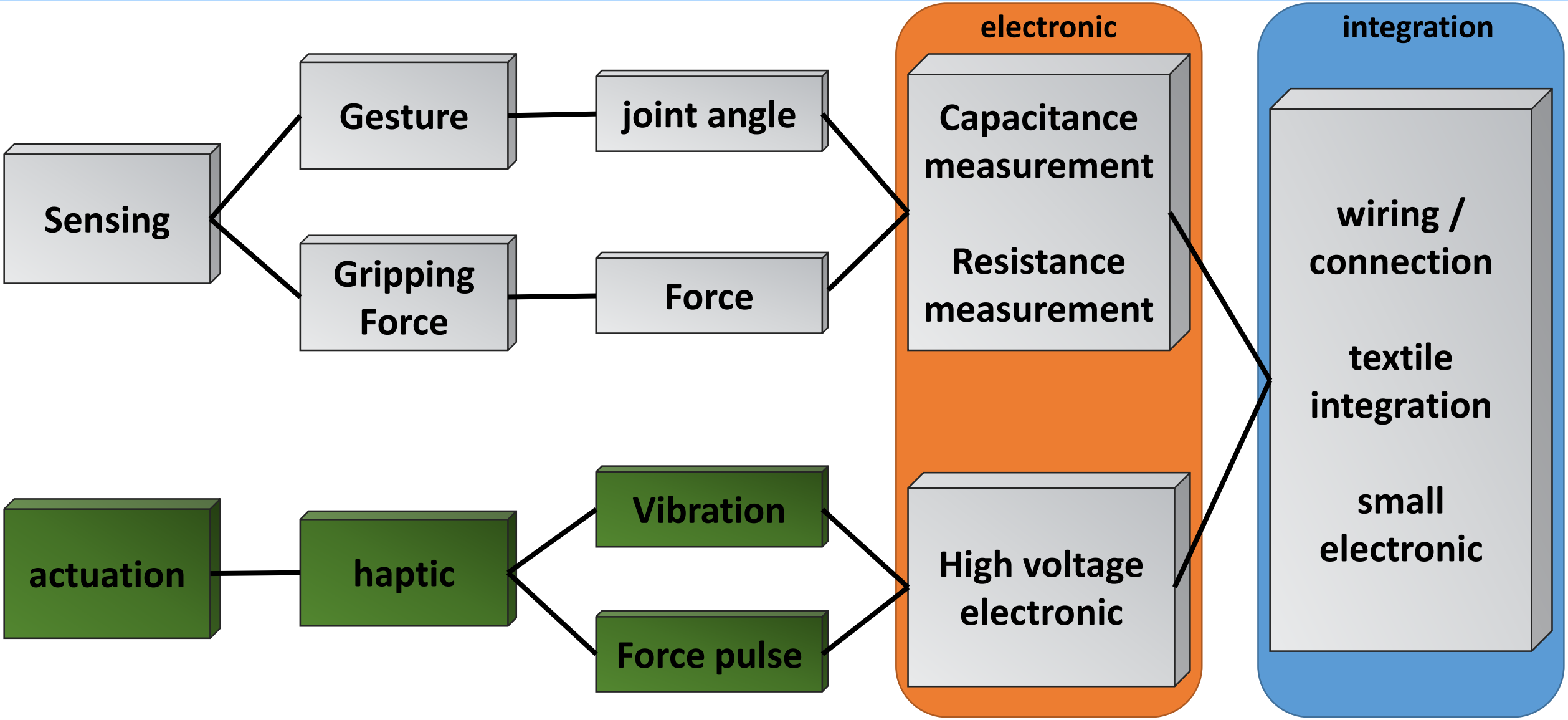
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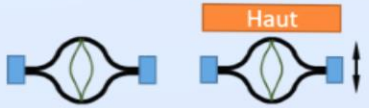
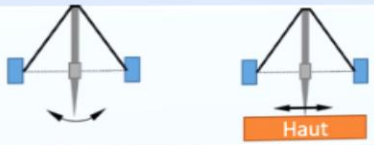
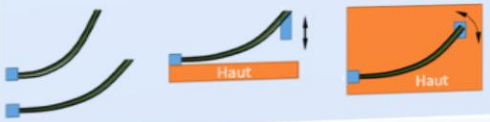
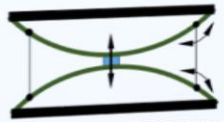
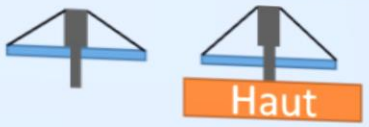
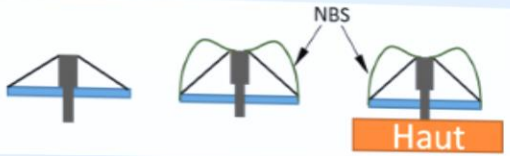
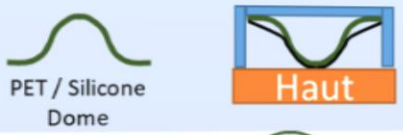
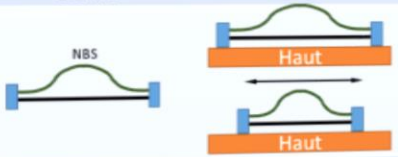
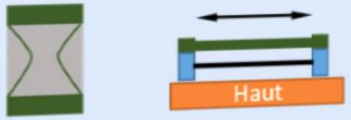
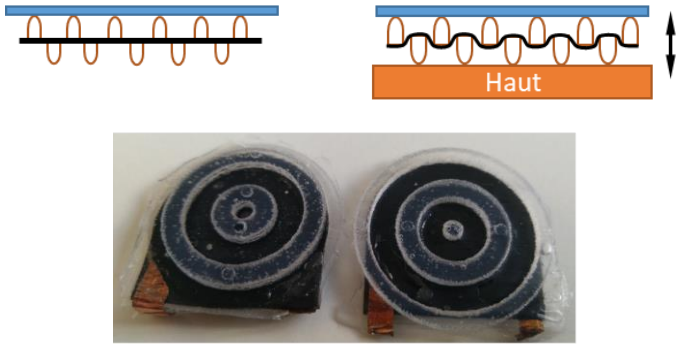
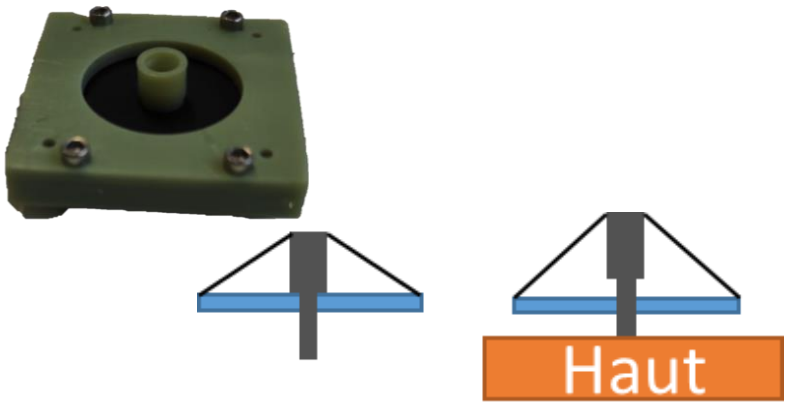
Haptic actuation concepts

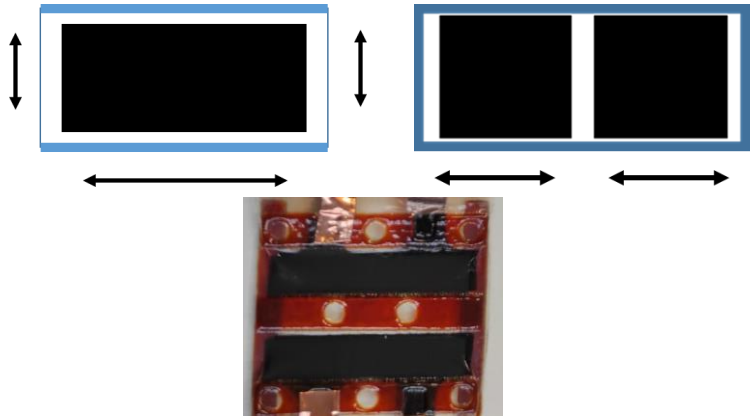
Geometrie / Messprinzip	Nr.	Beschreibung	Intensität	Komplexität	Flachbau
	7	Strukturierter DE (orth. Kraftwirkung)			
	8	DE mit vorgeformter Silikonschicht (orth. Kraftwirkung)			
	9	DE mit innerem Vorspannmech. (orth. Kraftwirkung)			
	10	Segmentierter DE (tang. und orth. Kraftwirkung)			
	11	Biegebalken mit DE (tang. und orth. Kraftwirkung)			
	12	Gegeneinader gespannte NBS (tang. Kraftwirkung)			

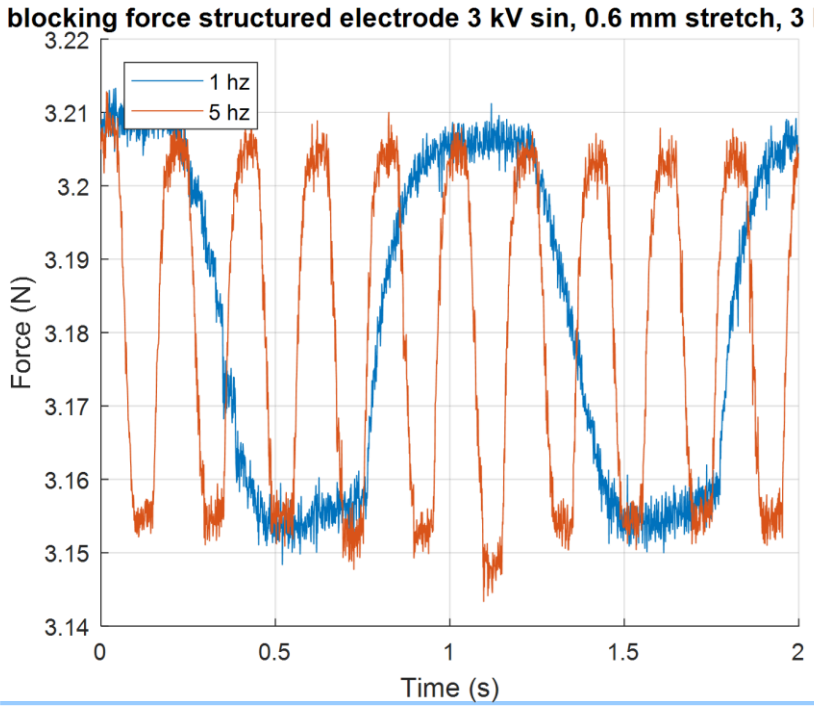
Geometrie / Messprinzip	Nr.	Beschreibung	Intensität	Komplexität	Flachbau
	1	DE Vorgespannt (orth. Kraftwirkung)			
	2	DE mit NBS (orth. Kraftwirkung)			
	3	PET / Silikon Dom als Vorspannmech. (orth. Kraftwirkung)			
	4	NBS und DE in Balkenrichtung (tang. Kraftwirkung)			
	5	Siehe 4 aber NBS in Ebene (tang. Kraftwirkung)			
	6	2 NBs in Ebene (tang. Kraftwirkung)			

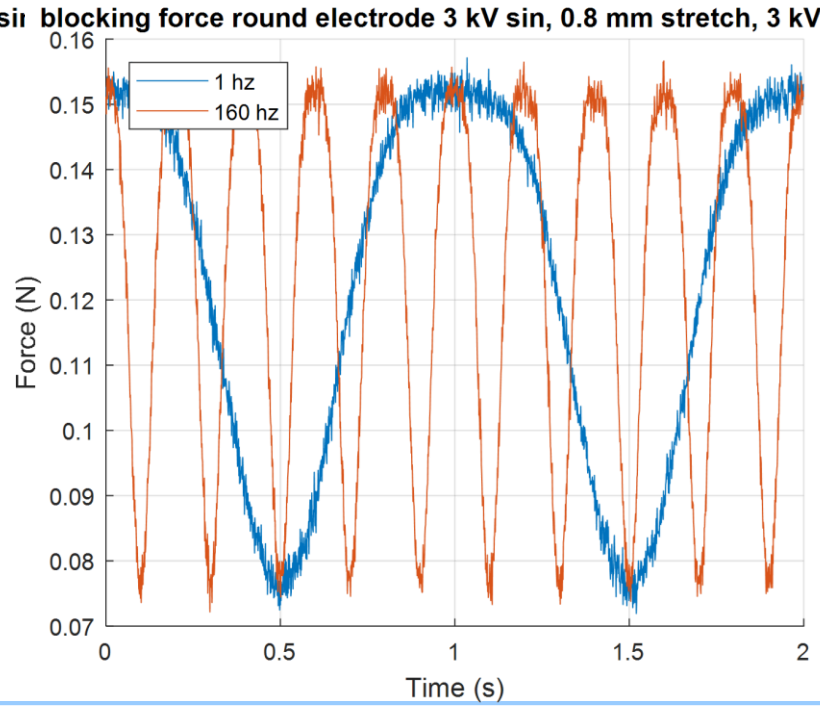
Sinusoidal input signal – Force response

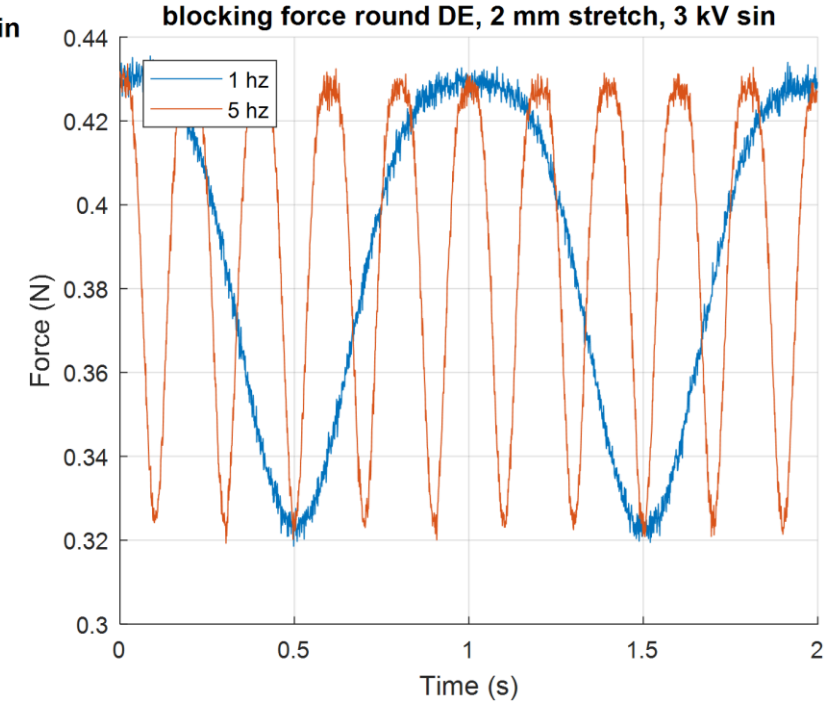




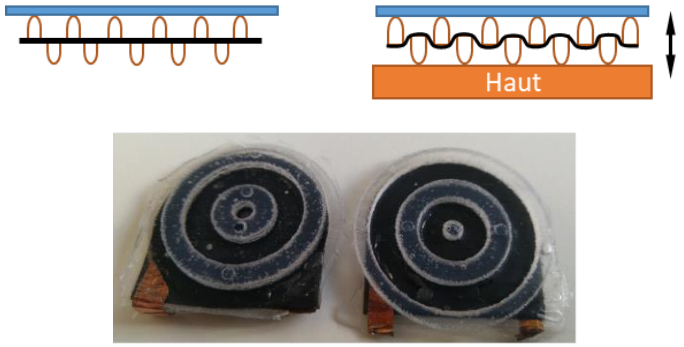


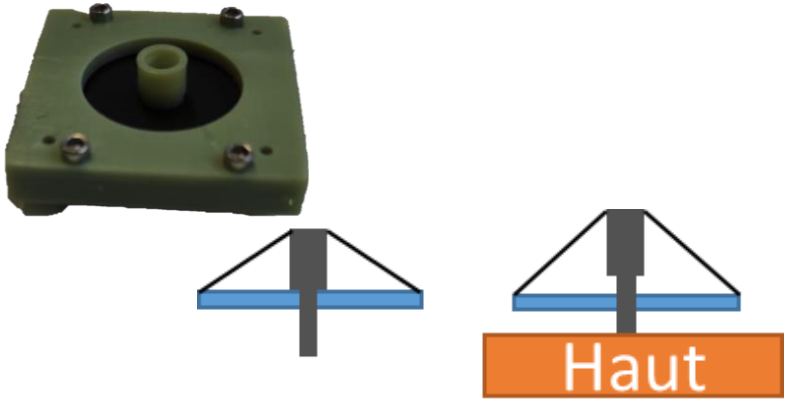


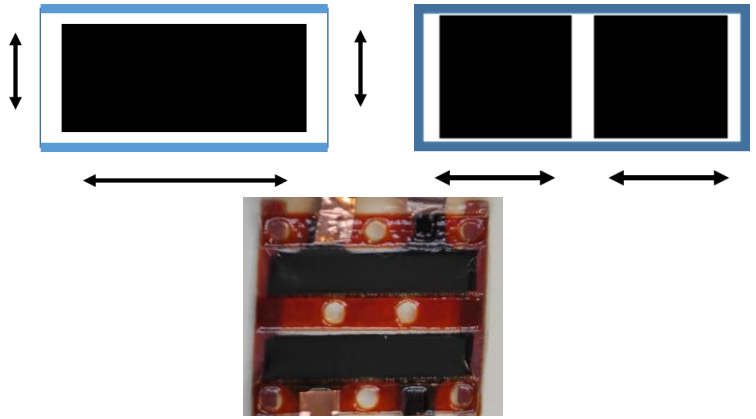


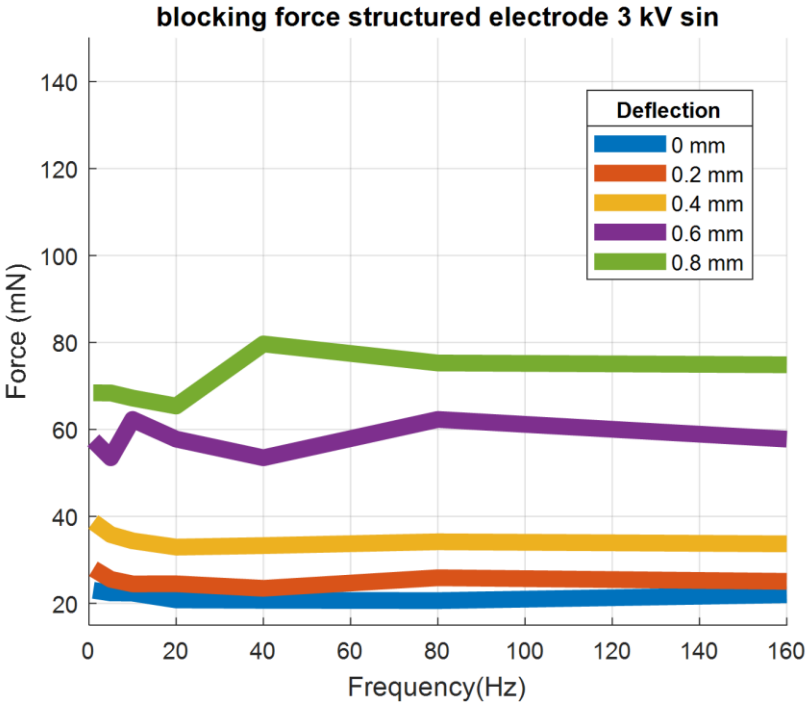


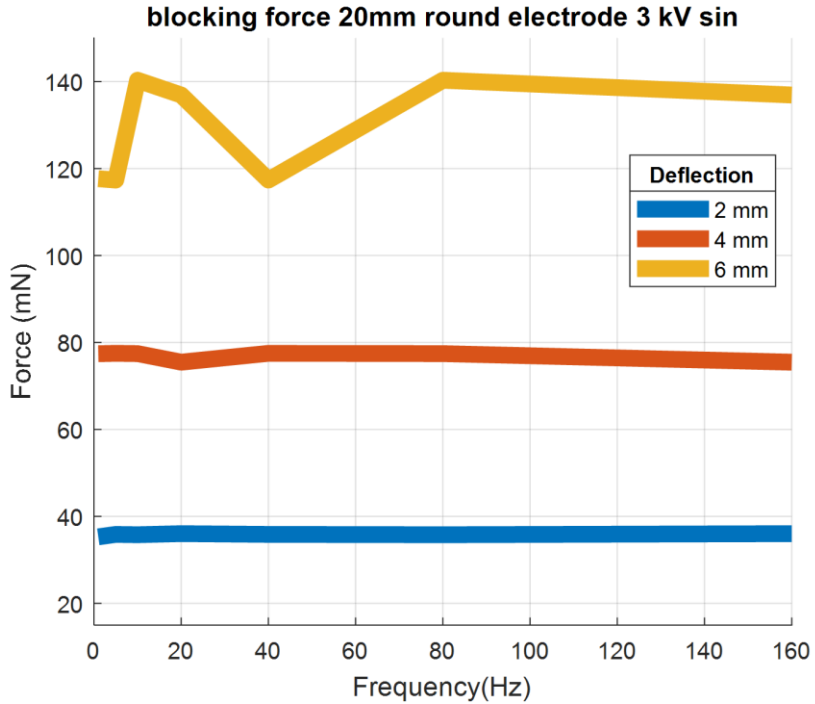
Sinusoidal input signal – Force difference

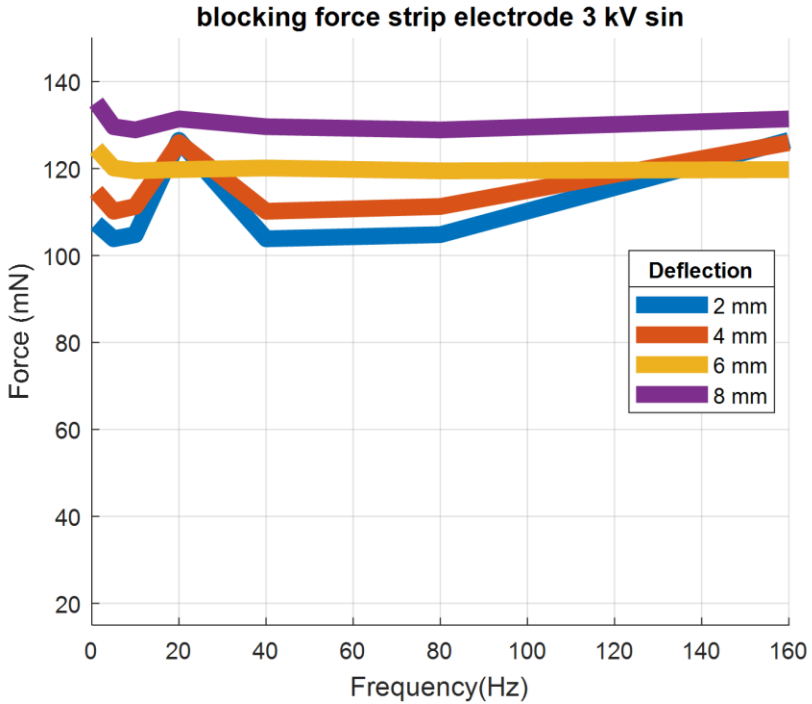




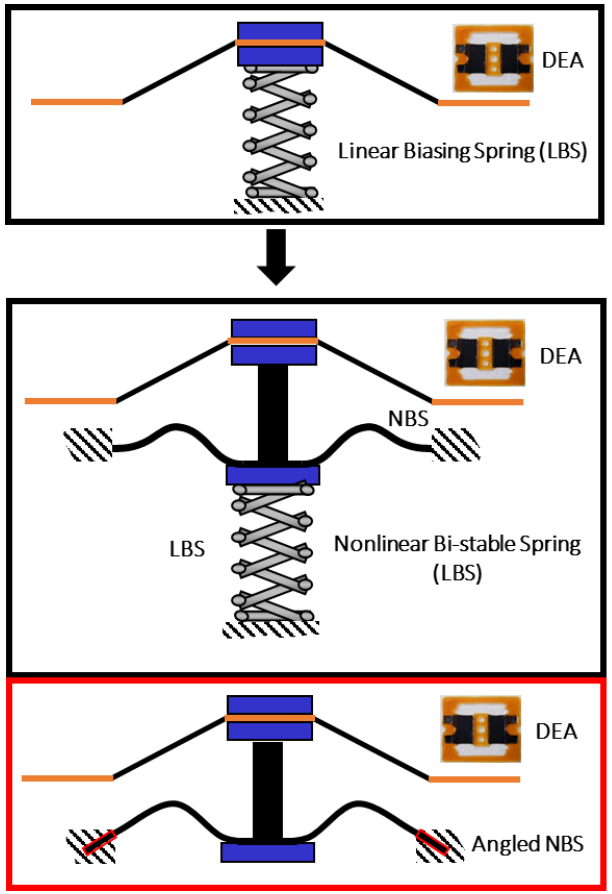


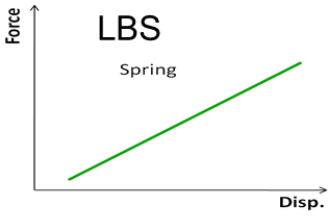


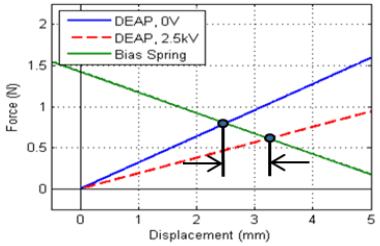


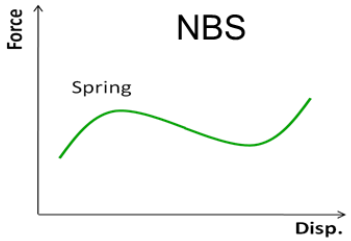


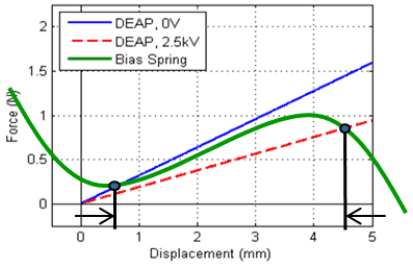
Nonlinear bias spring (NBS)



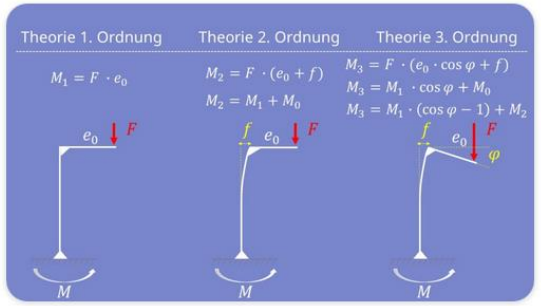




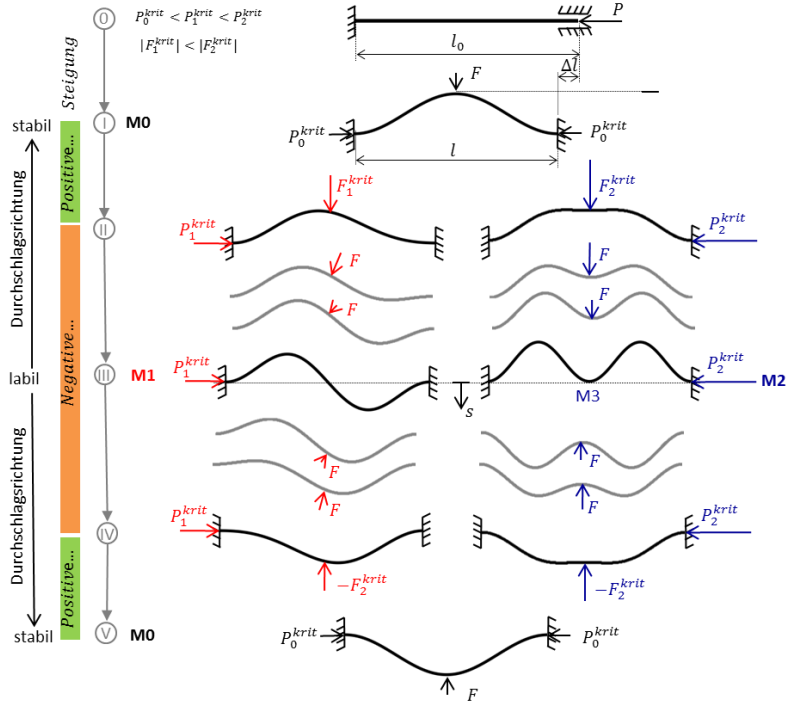




Beam theory for NBS calculation

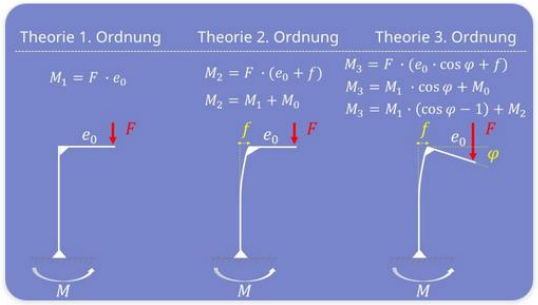


Bending deformation of fixed end beams



Nonlinear bias spring (NBS)

Beam theory for NBS calculation



Euler beam equation

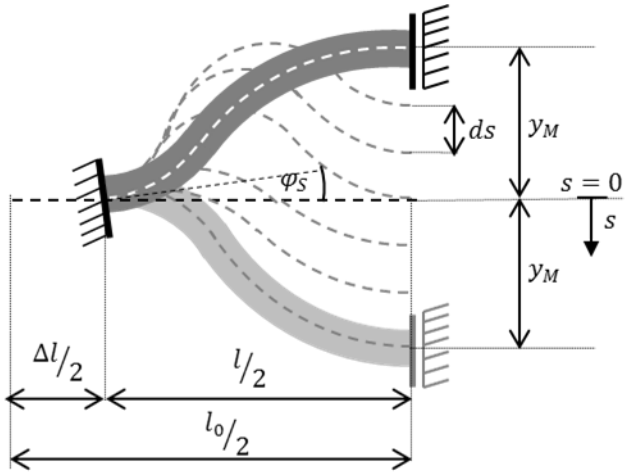
$$\frac{d^4}{dx^4}\omega(x) + \lambda^2 \frac{d^2}{dx^2}\omega(x) = 0 \quad \text{with} \quad \lambda^2 = \frac{P}{E_B I_y}.$$

Euler beam – extension acc. Vangbo et al.

$$F(\eta) = \frac{-4(\eta l)^2 E_B I_y}{l^3 \sqrt{3 - \frac{12}{\eta l}\tan(\frac{\eta l}{4}) + \tan^2\left(\frac{\eta l}{4}\right)}} \sqrt{\left(\Delta l - \Delta l_p(\eta)\right) l}$$

$$s(\eta) = -\frac{l^3 F(\eta)}{(\eta l)^2 E_B I_y}\left[\frac{1}{4} - \frac{1}{\eta l}\tan\left(\frac{\eta l}{4}\right)\right] \qquad \eta^2 = \frac{P}{E_B I_y}.$$

FE Simulation



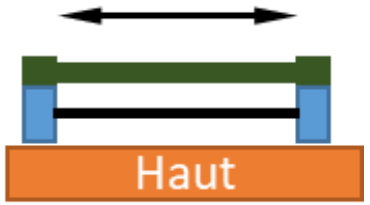
$$Compression: \; c = \frac{l_0 - \Delta l}{l_0} = \frac{l}{l_0}$$

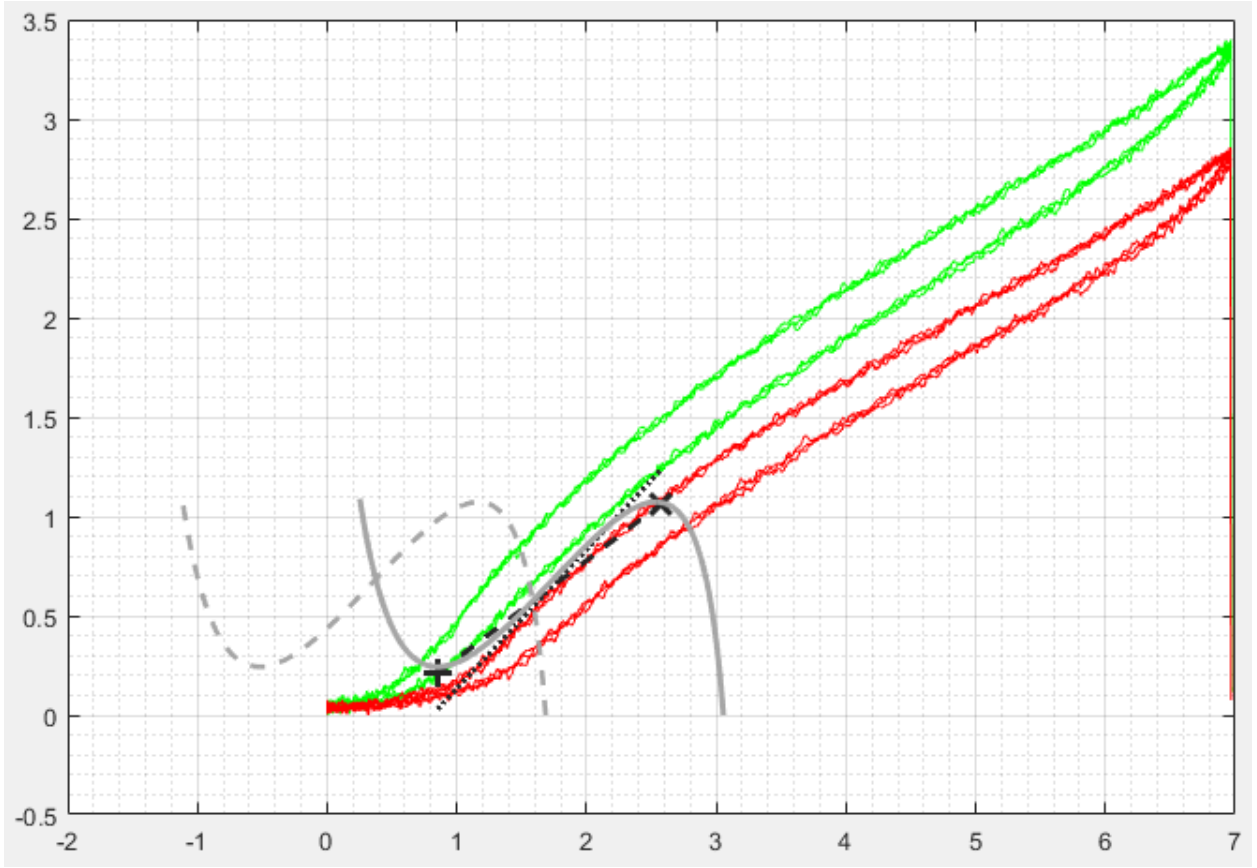
$$Natural\ Angle: \; \phi_N$$

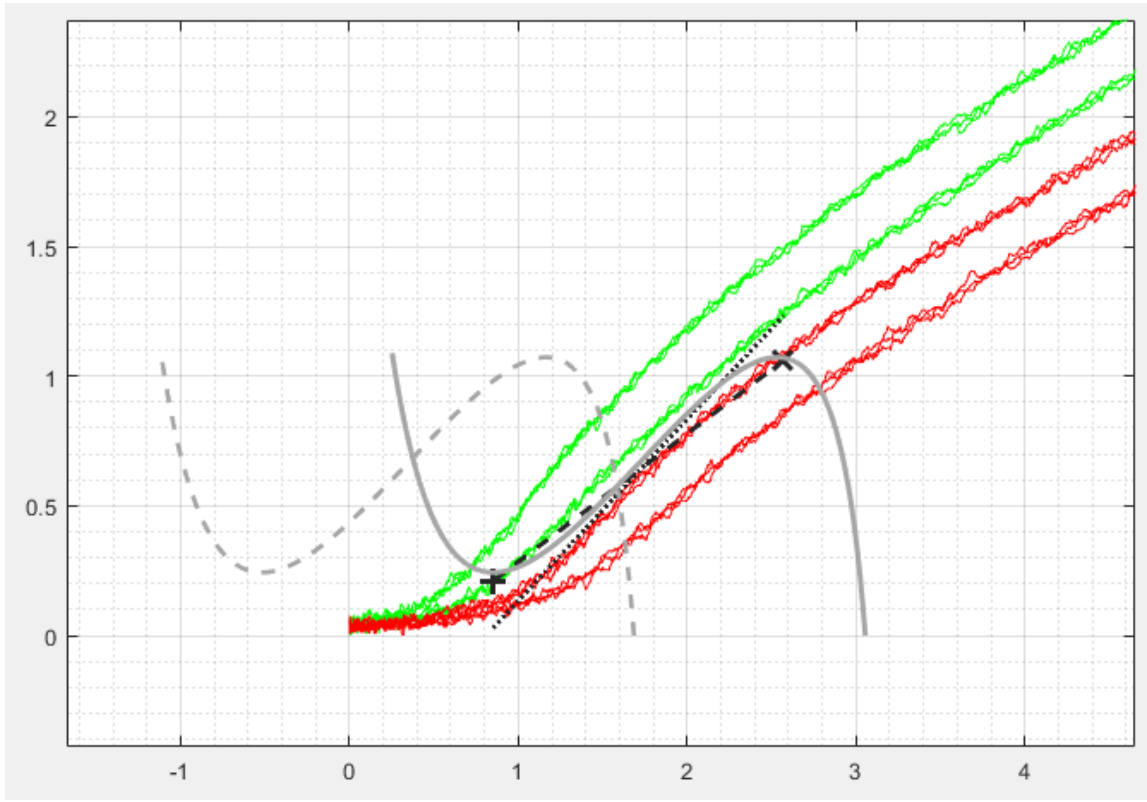
$$Setting\ Angle: \; \phi_S$$

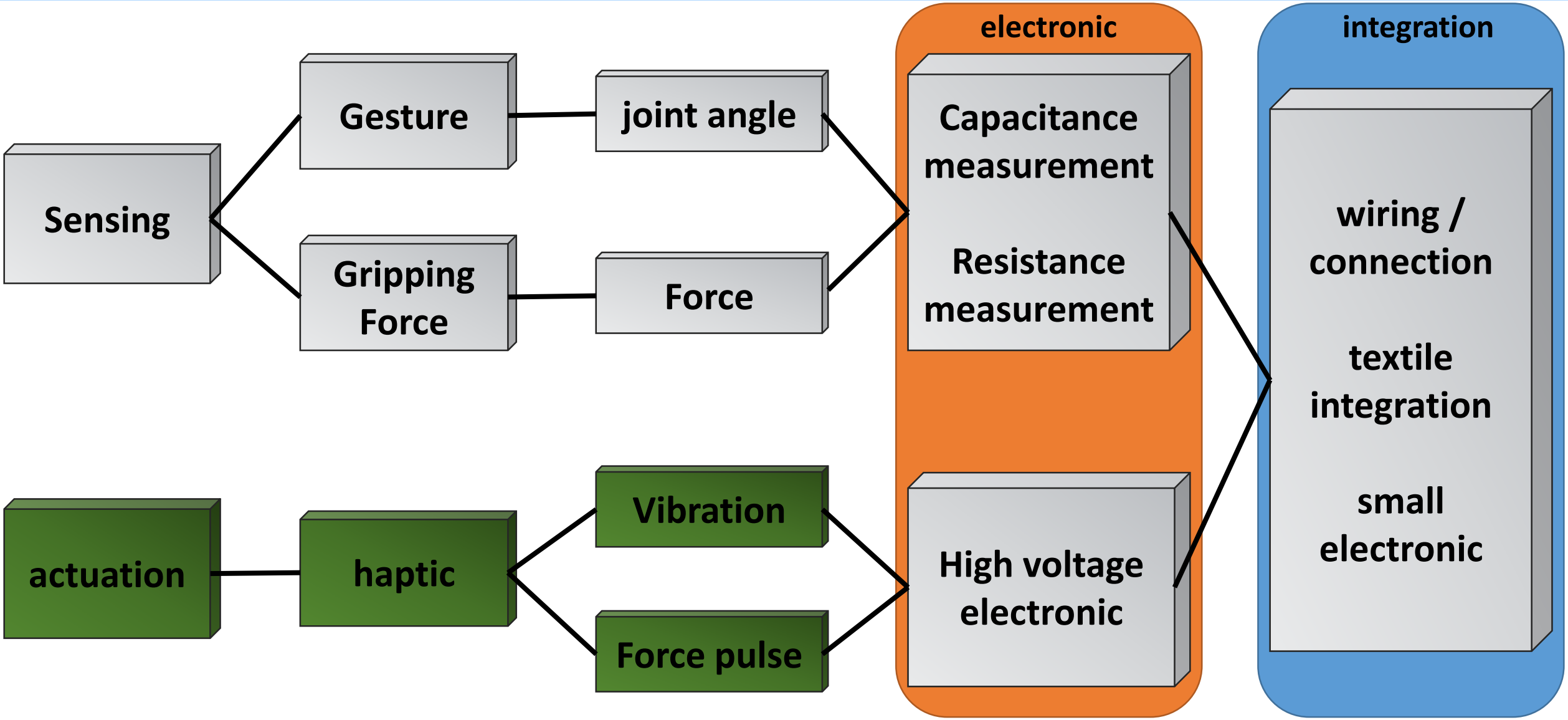
$$Stroke - Increment: ds$$

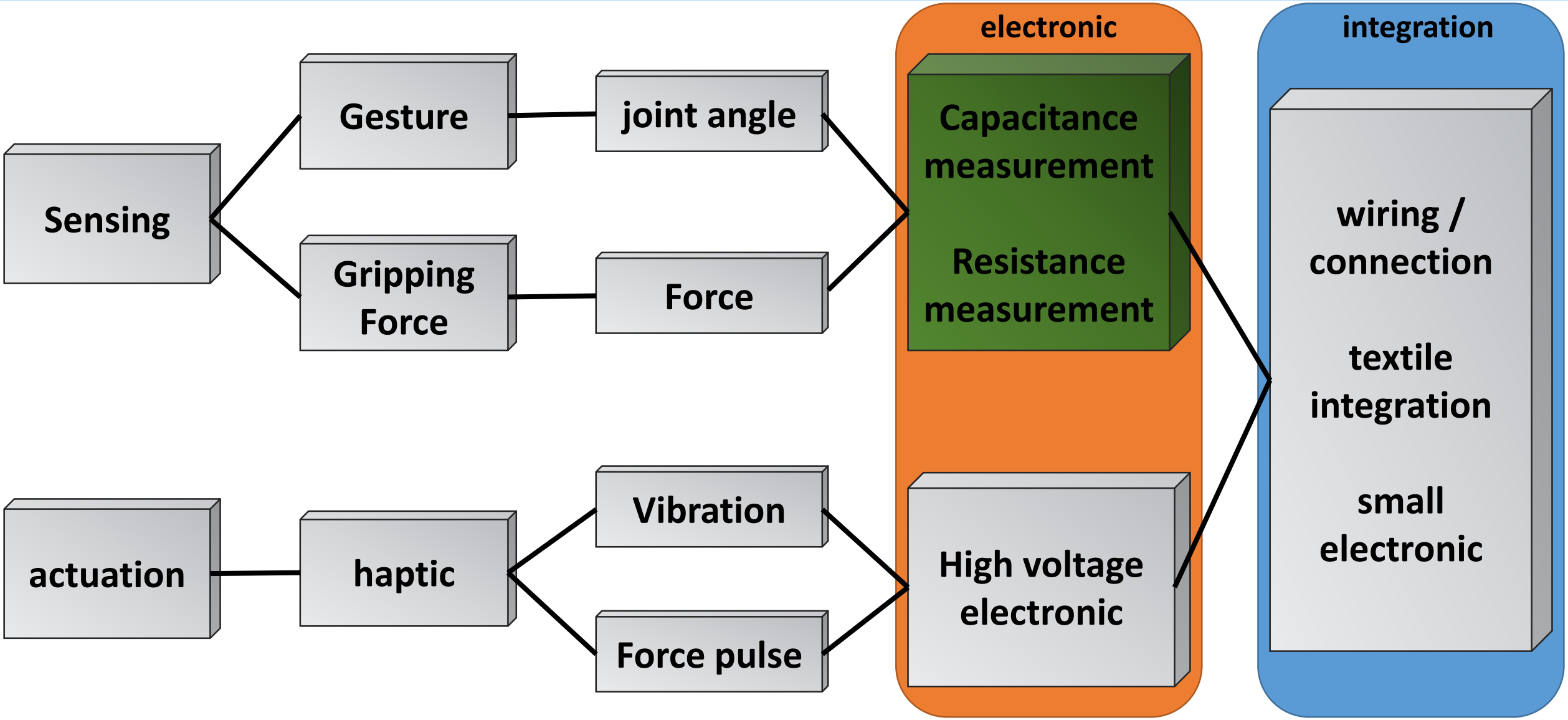
NBS calculation and system design








Sensing
Gesture
joint angle
Gripping Force
Force
actuation
haptic
Vibration
Force pulse
electronic
Capacitance measurement
Resistance measurement
High voltage electronic
integration
wiring / connection
textile integration
small electronic


Sensing
Gesture
joint angle
Gripping Force
Force
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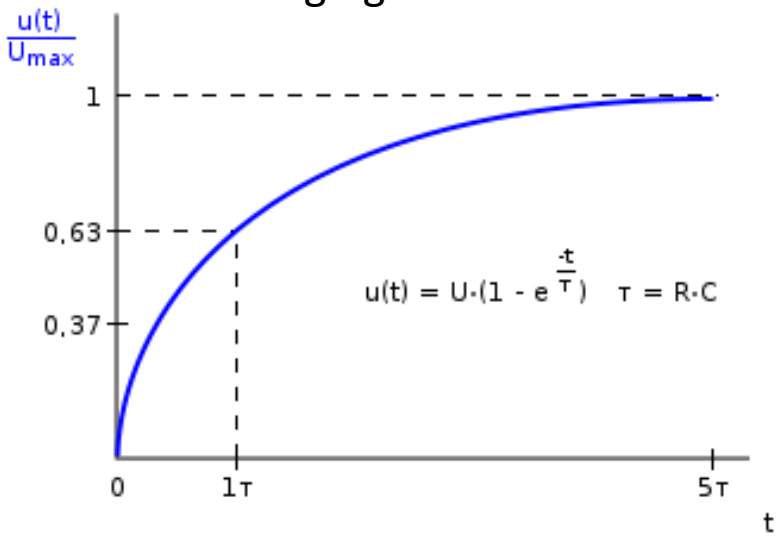
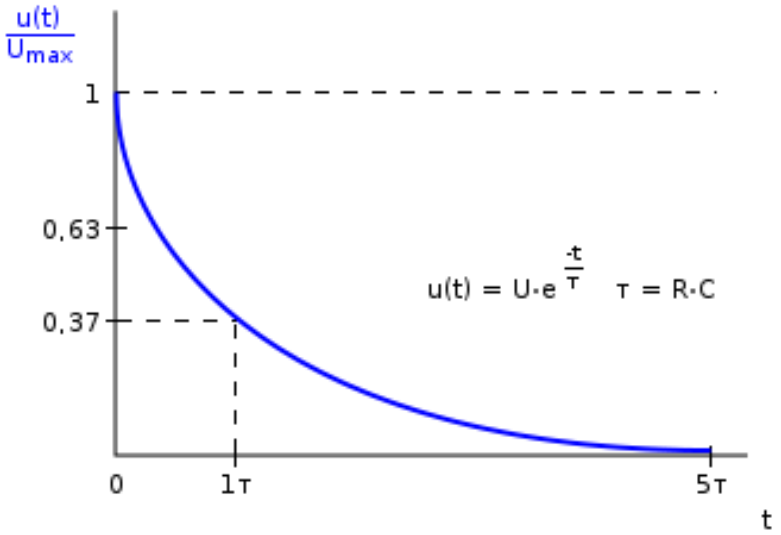
haptic
Vibration
Force pulse
electronic
Capacitance measurement
Resistance measurement
High voltage electronic
integration
wiring / connection
textile integration
small electronic

Capacitance measurement

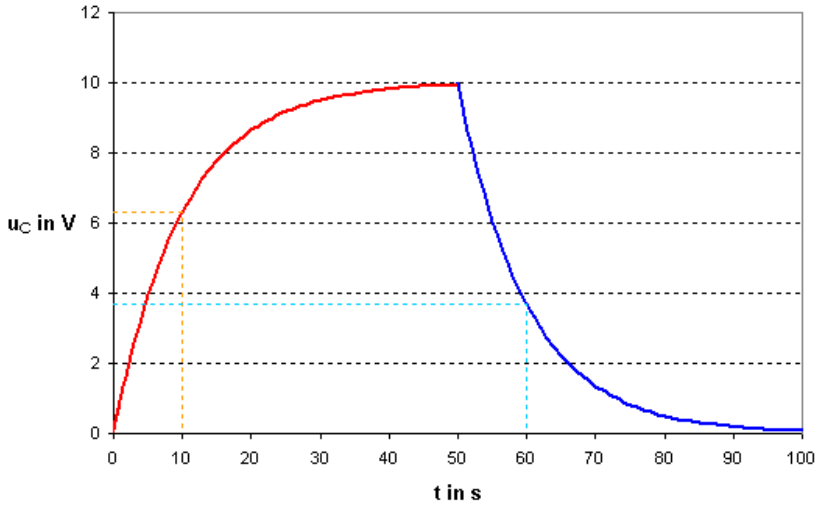
Charging Curve



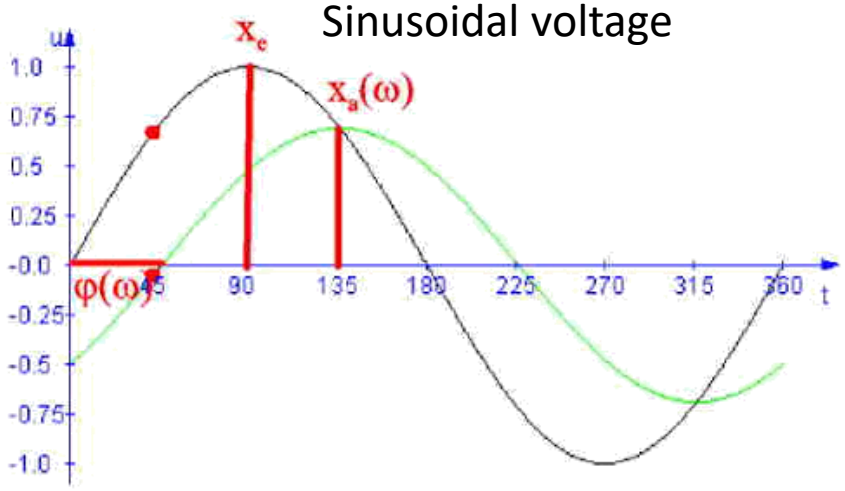
Discharging Curve



combination

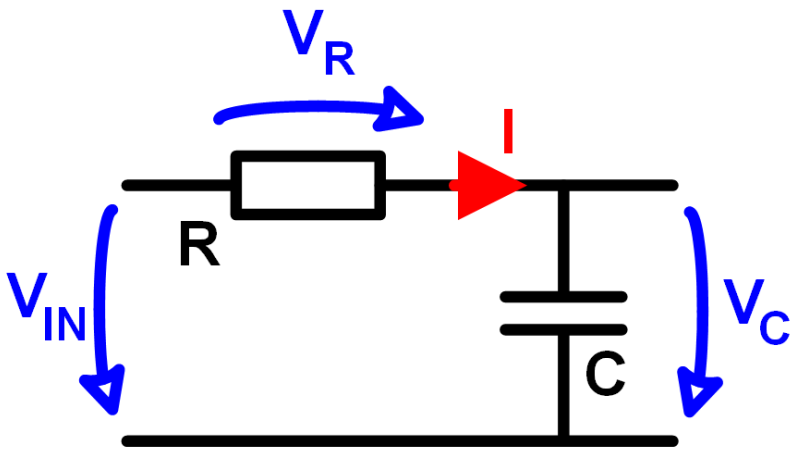


Sinusoidal voltage

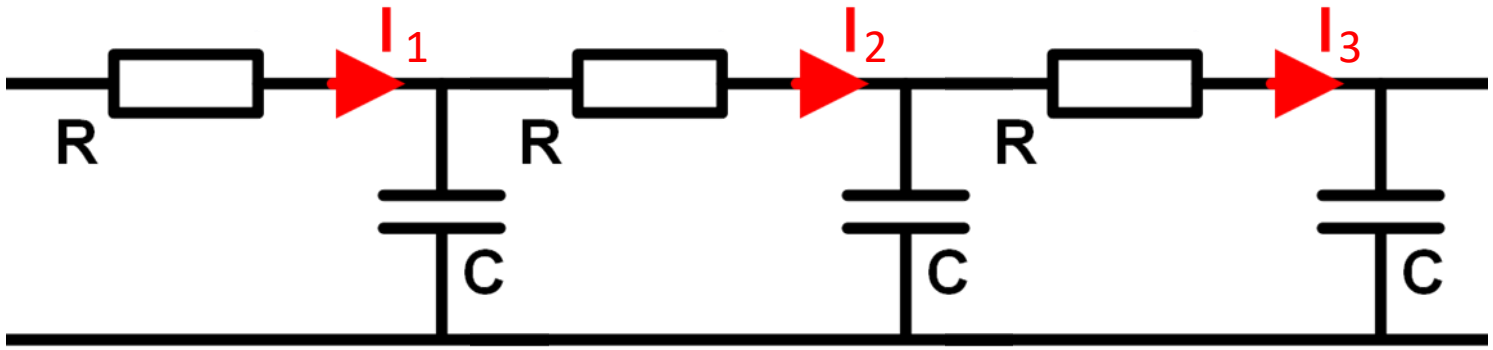


Problem with real DE measurement

Real Capacitor



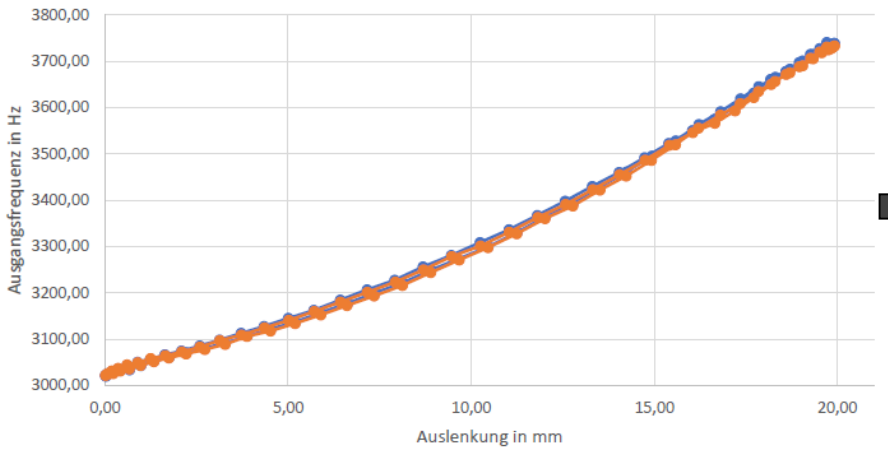
DE

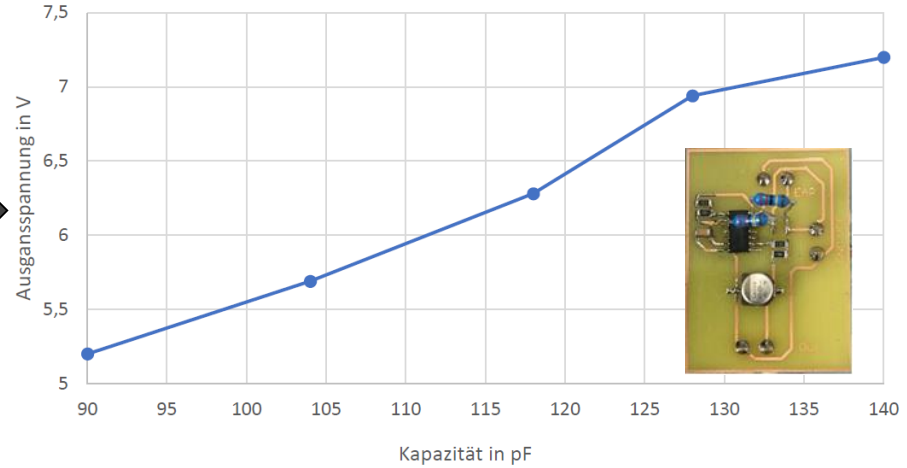


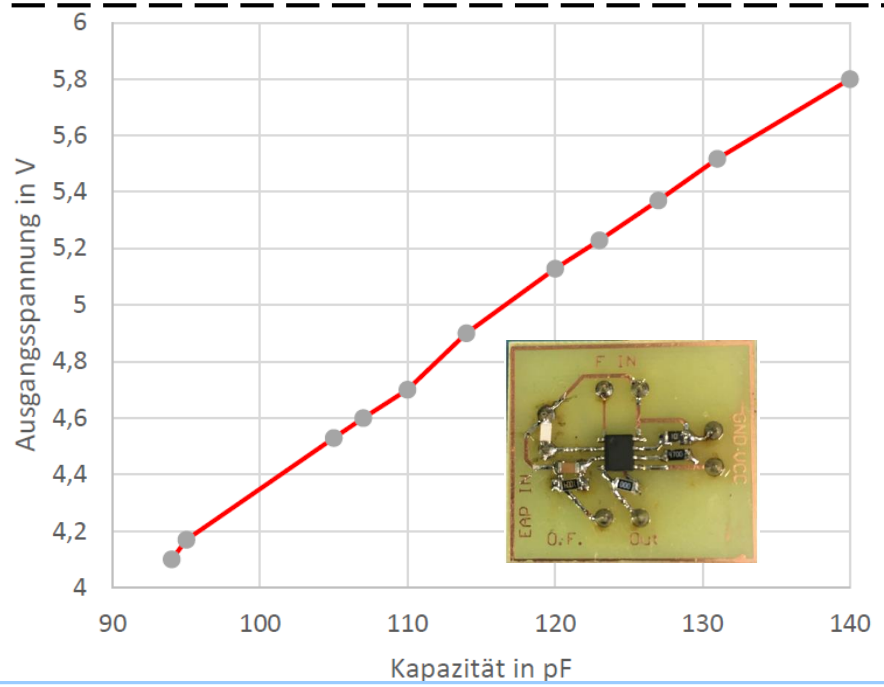
- 1 Resistance and 1 Capacity
- Relative low Resistance

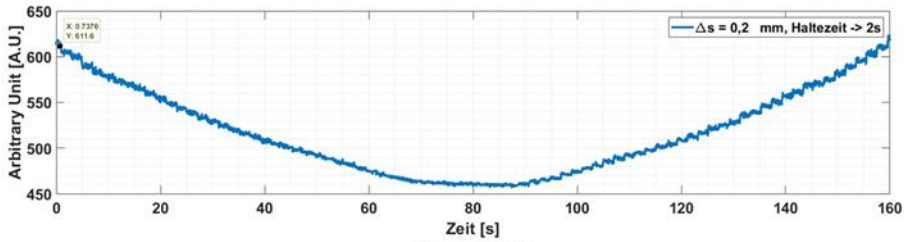
- more Resistances, more Capacities
- Relative high Resistance

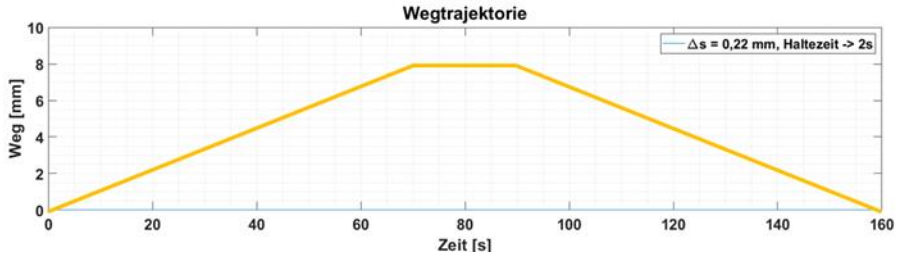
Difficult to measure the capacitance with the standard measurement circuits

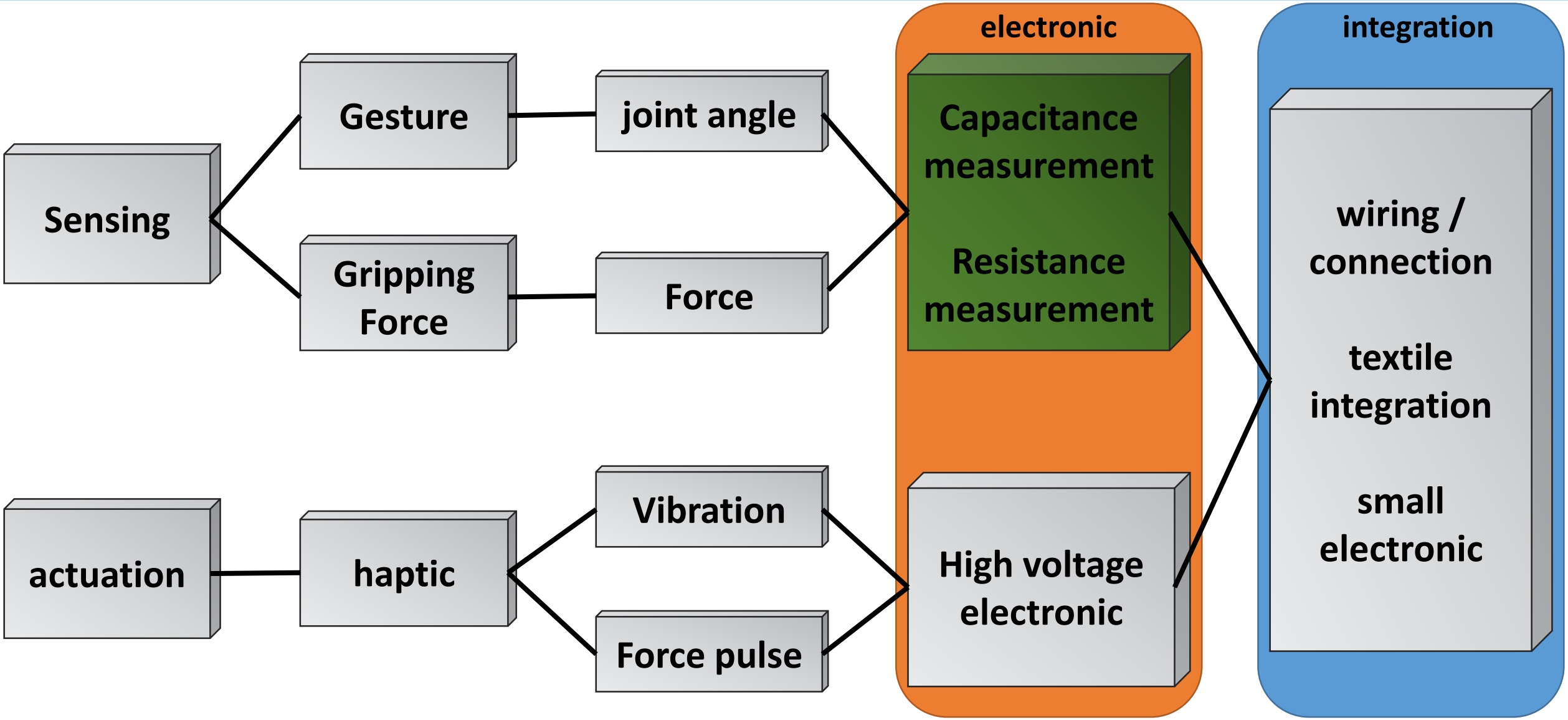

Ausgangsfrequenz in Hz
3800,00
3700,00
3600,00
3500,00
3400,00
3300,00
3200,00
3100,00
3000,00
0,00
5,00
10,00
15,00
20,00
Auslenkung in mm

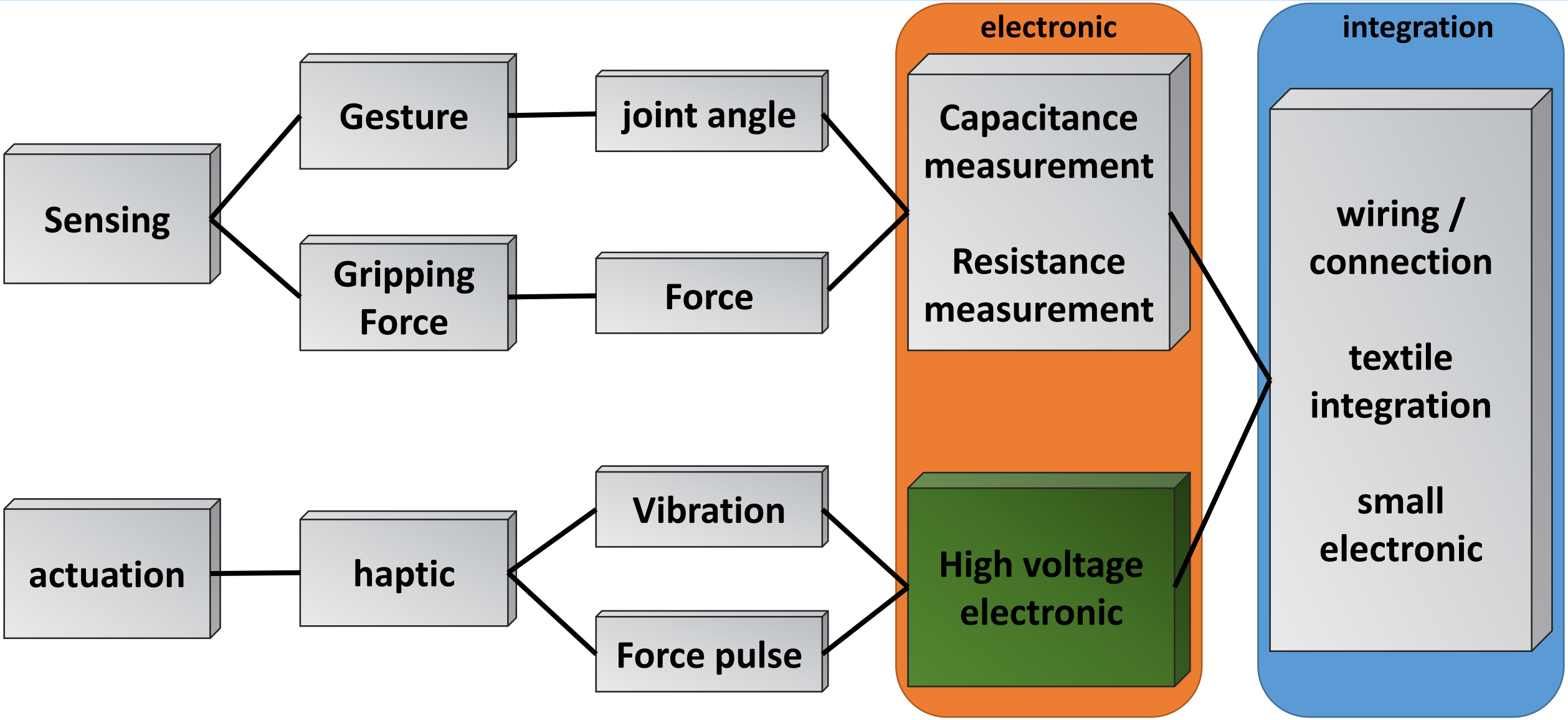

Ausgangsspannung in V
7,5
7
6,5
6
5,5
5
90
95
100
105
110
115
120
125
130
135
140
Kapazität in pF

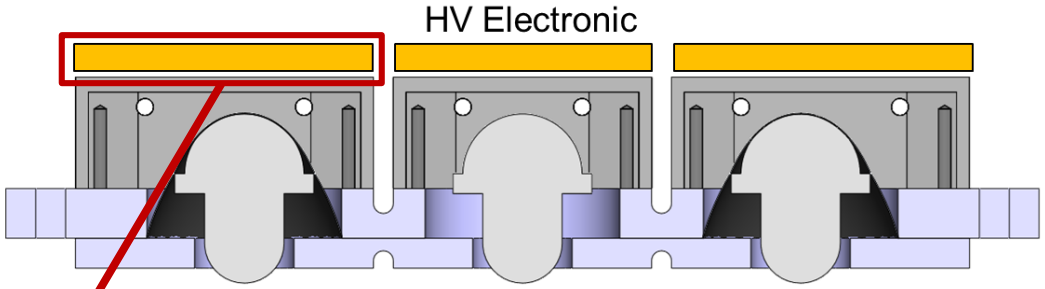

Ausgangsspannung in V
6
5,8
5,6
5,4
5,2
5
4,8
4,6
4,4
4,2
4
90
100
110
120
130
140
Kapazität in pF

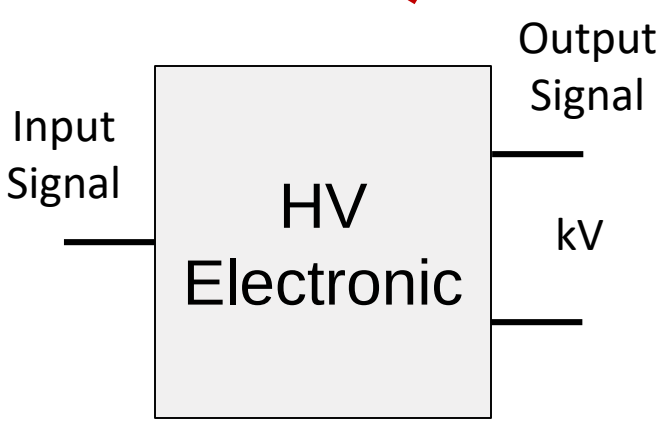

Δs = 0,2 mm, Haltezeit -> 2s
Arbitrary Unit [A.U.]
650
600
550
500
450
0
20
40
60
80
100
120
140
160
Zeit [s]


Wegtrajektorie
Δs = 0,22 mm, Haltezeit -> 2s
Weg [mm]
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
Zeit [s]


Sensing
Gesture
joint angle
Gripping Force
Force
actuation
haptic
Vibration
Force pulse
electronic
Capacitance measurement
Resistance measurement
High voltage electronic
integration
wiring / connection
textile integration
small electronic

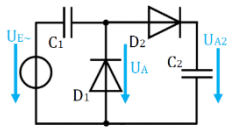

Sensing
Gesture
joint angle
Gripping Force
Force
actuation
haptic
Vibration
Force pulse
electronic
Capacitance measurement
Resistance measurement
High voltage electronic
integration
wiring / connection
textile integration
small electronic



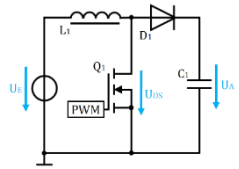


Possible realization

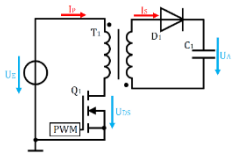
1.) Villard/Greinacher circuit (voltage doubler)



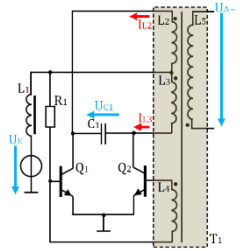
2.) StepUp-Converter (Boost-Converter)

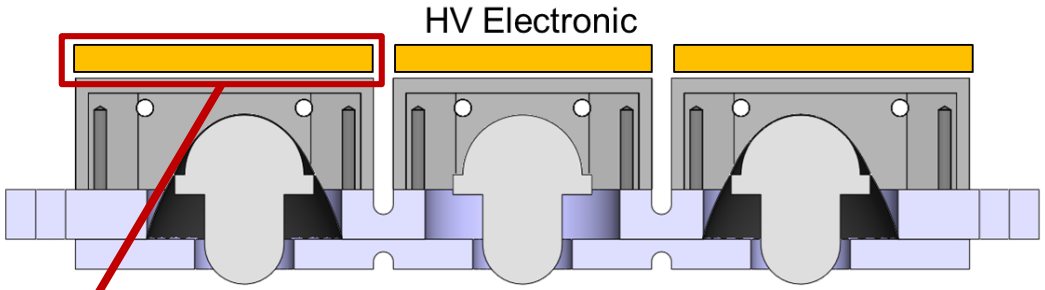


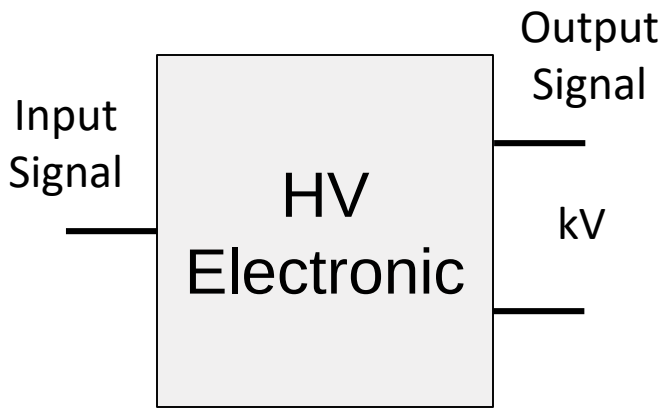
3.) Flyback converter



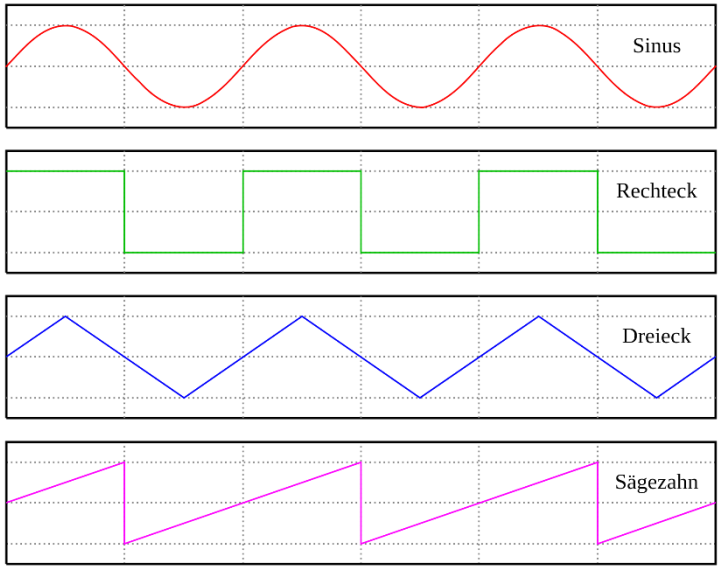
4.) Resonant converter



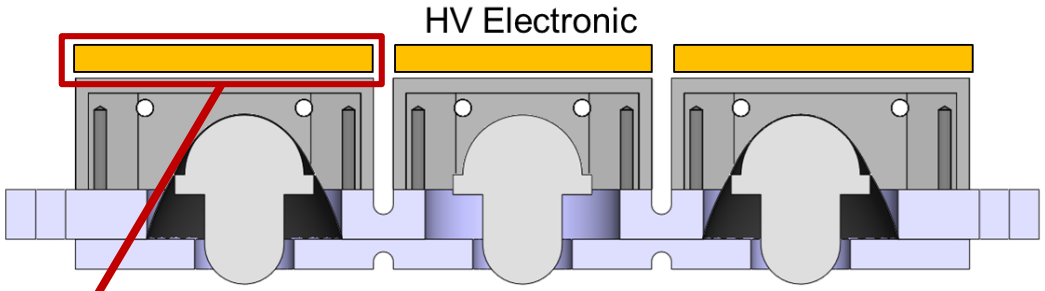




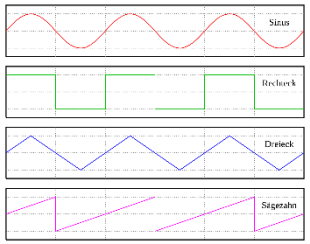
Exemplary Signal shapes

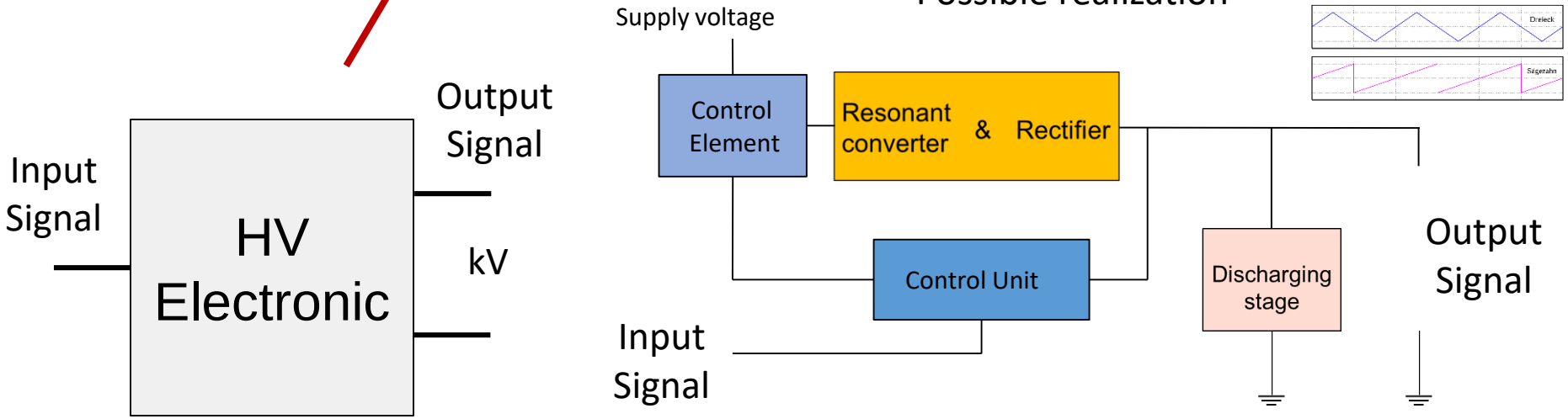


HV Electronic



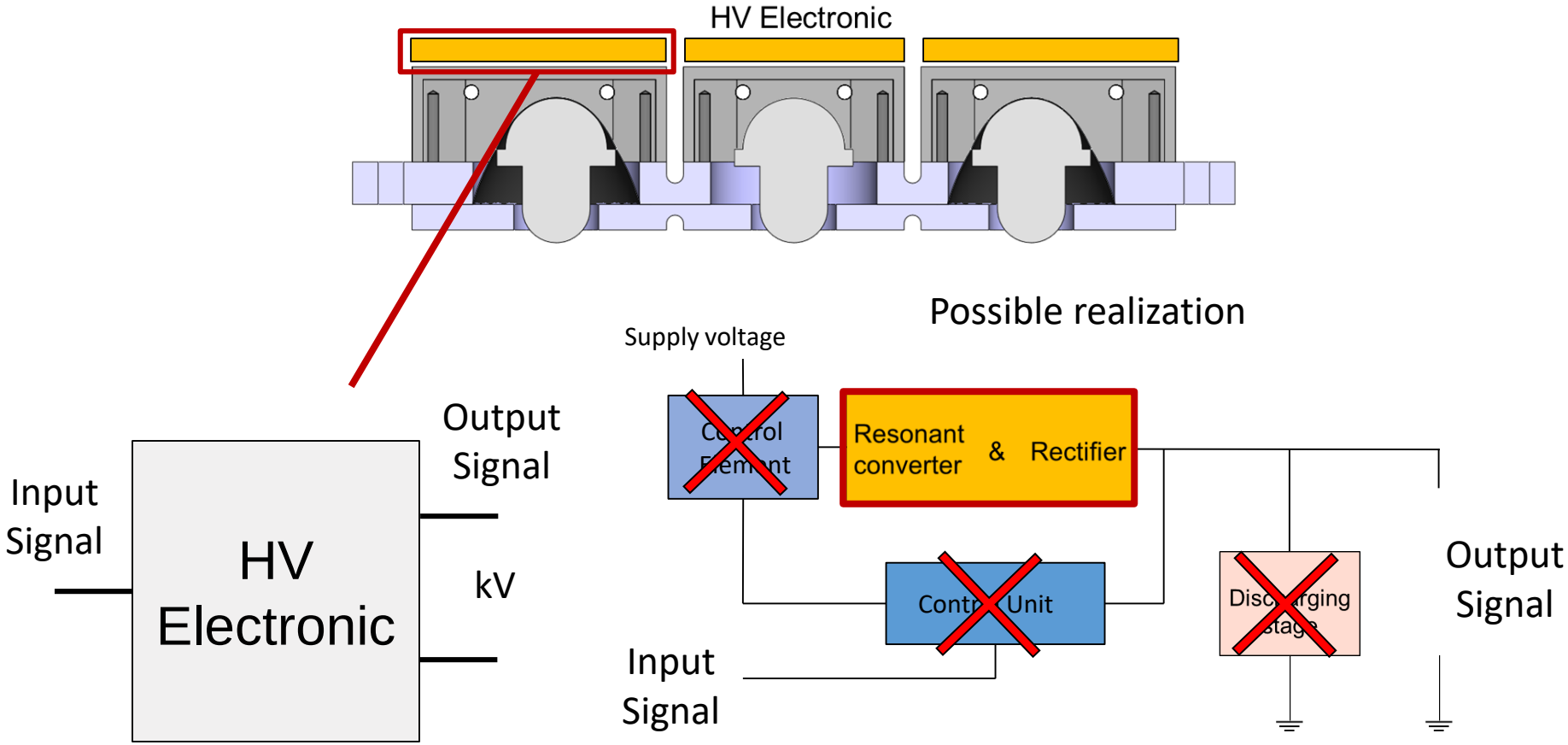
Possible realization



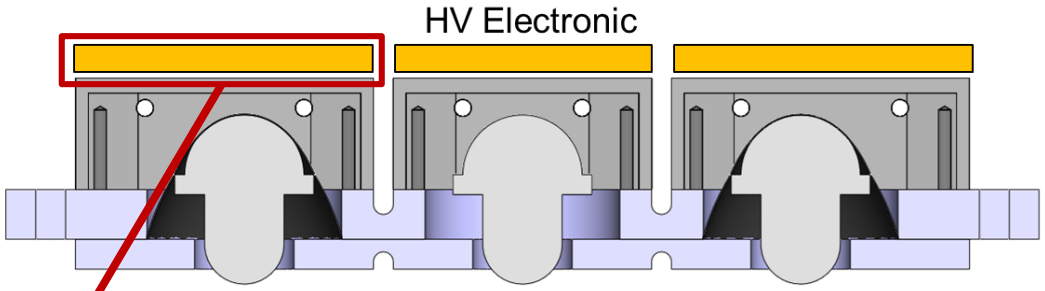


Relative complex circuit ➡ big size of the circuit

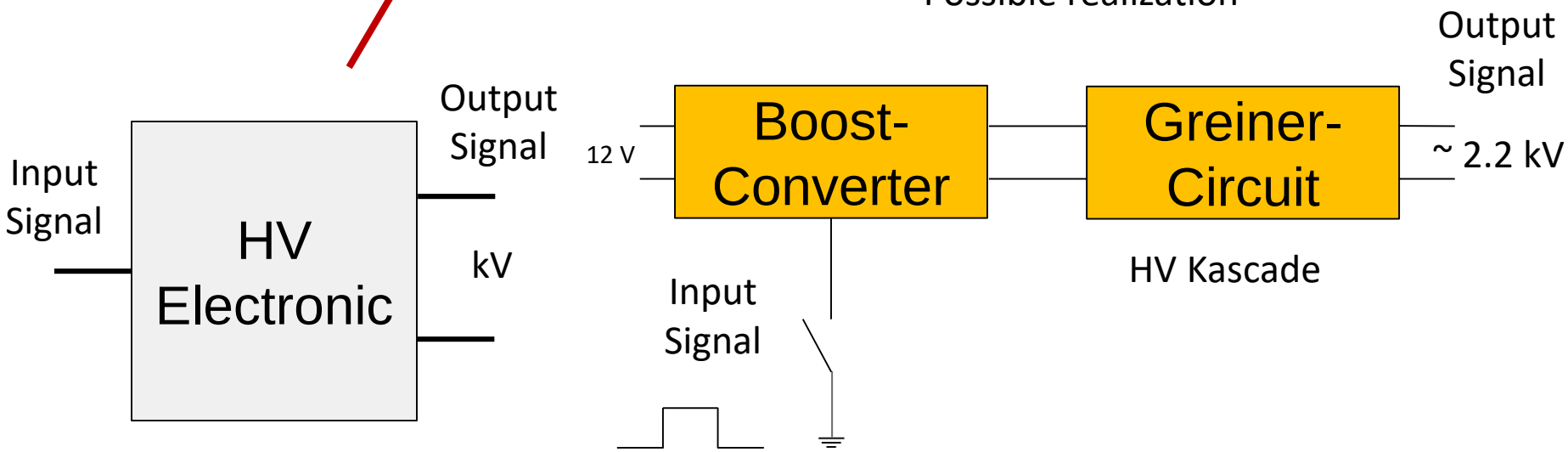
HV Electronic



OR



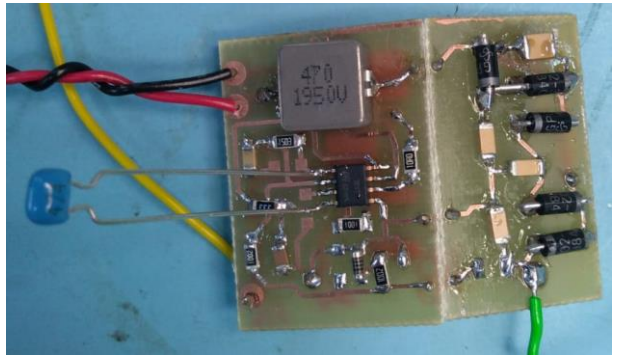
Possible realization

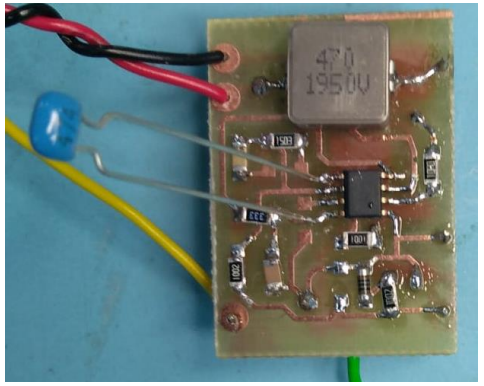


Relative simple circuit, small size of the circuit, rectangular or Peak Shape

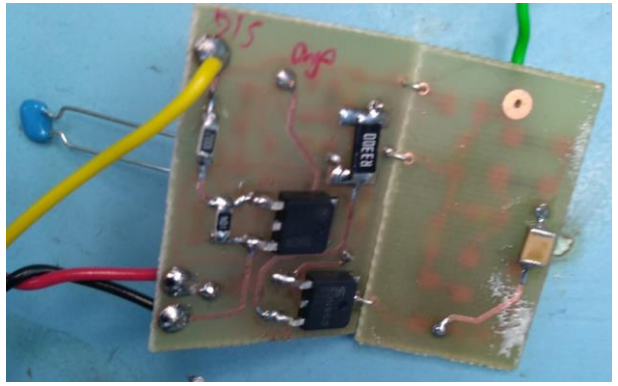
Electronic develpoment

front side

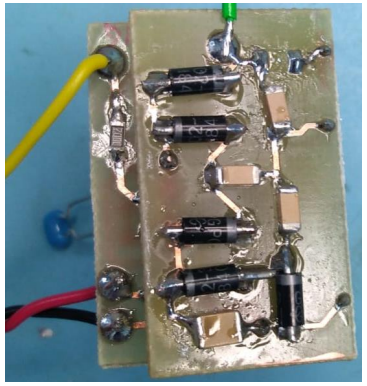


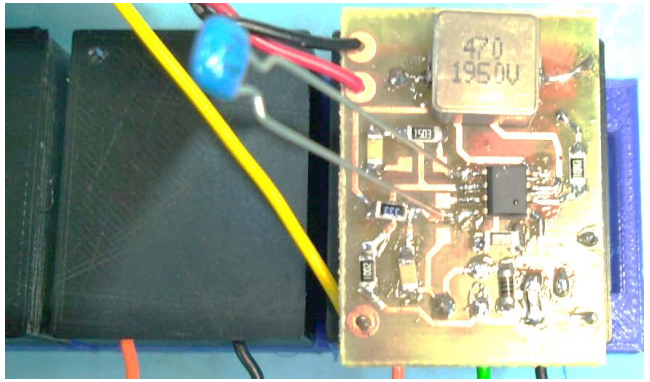


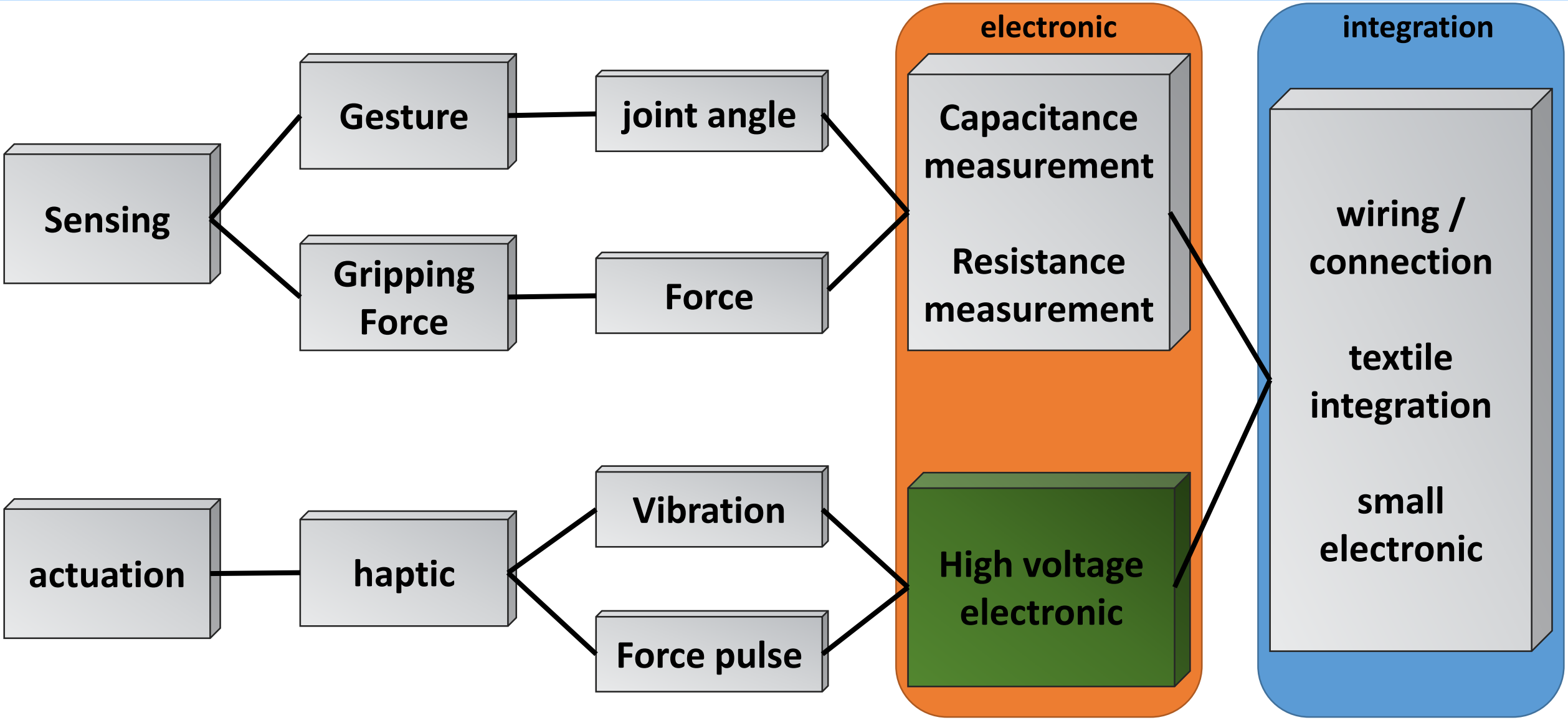
back side

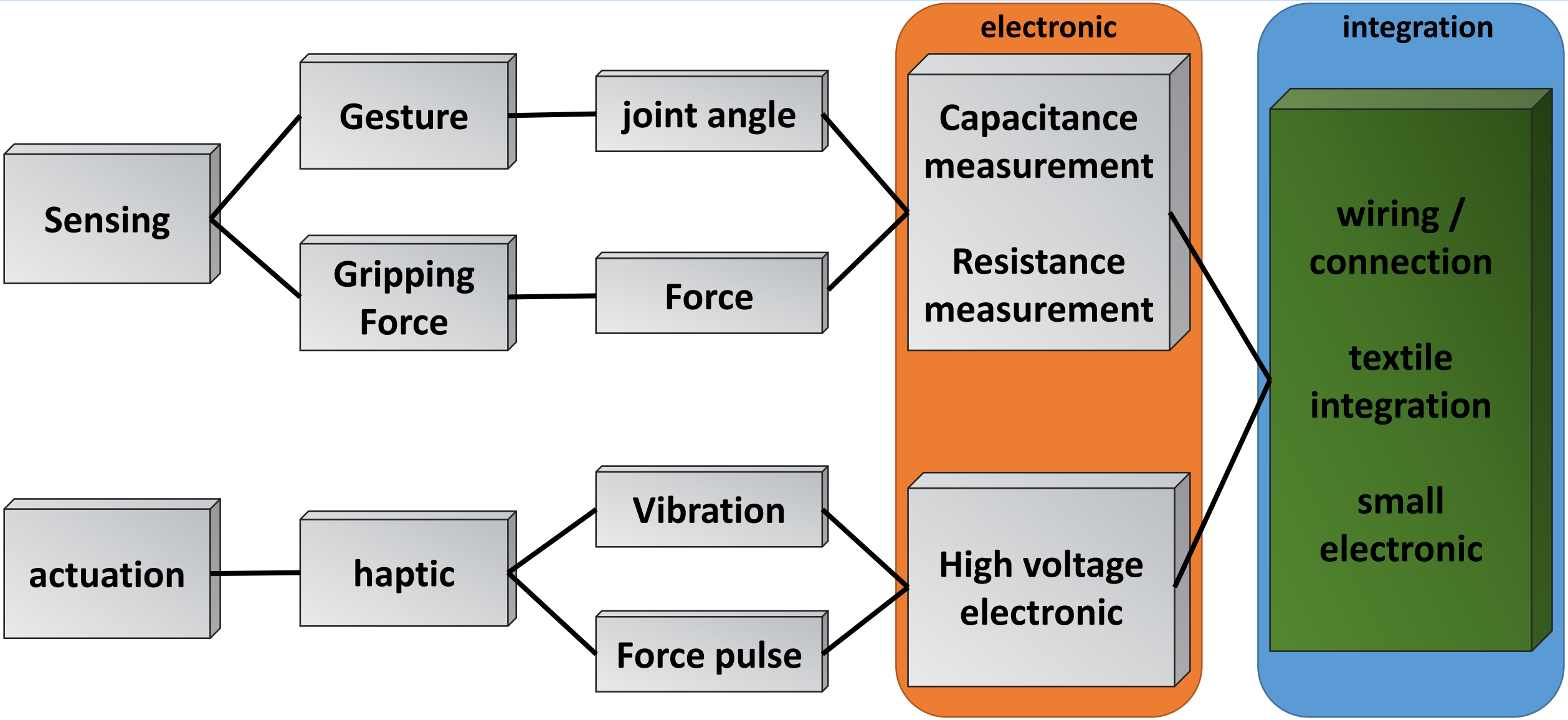


collapsible






Sensing
Gesture
joint angle
Gripping Force
Force
actuation
haptic
Vibration
Force pulse
electronic
Capacitance measurement
Resistance measurement
High voltage electronic
integration
wiring / connection
textile integration
small electronic


Sensing
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Vibration
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electronic
Capacitance measurement
Resistance measurement
High voltage electronic
integration
wiring / connection
textile integration
small electronic

Connection concepts - comparison

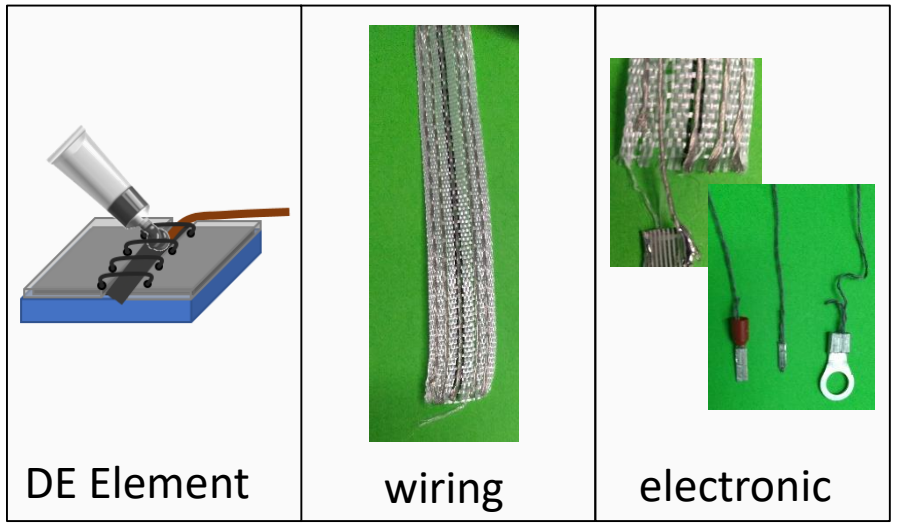
Contact concept	Glue	Glue + put trough	Cupper tape	Cupper + soldering	Metal layer + soldering
Costs					
Contact resistance					
Mechanical connection (stiffness/flexibility)					
Integrability					
Comfort					
complexity					
Fatigue strength					

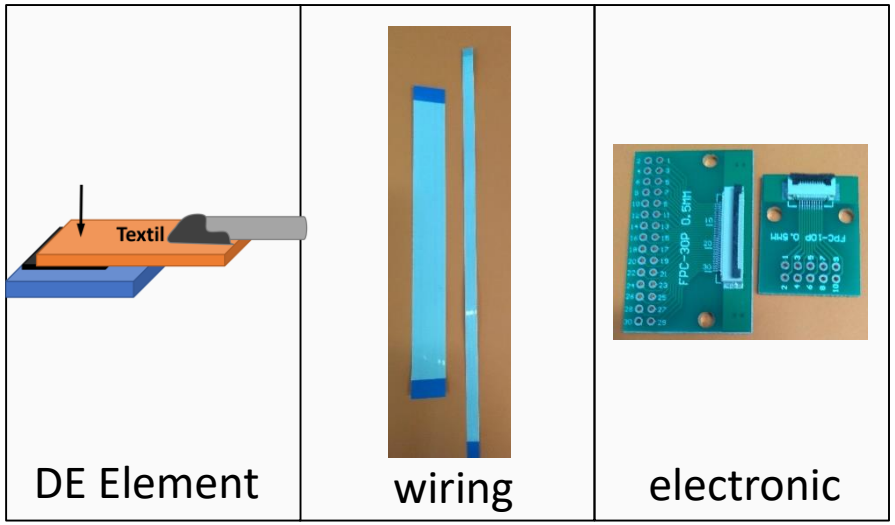
Contact concept	Metal + sewing	sewing + Finger structure	Between silicone layer an electrode	Sewing onto the electrode	glue + sewing
Costs					
Contact resistance					
Mechanical connection (stiffness/flexibility)					
Integrability					
Comfort					
complexity					
Fatigue strength					

Contact concept	Conductive textile + sewing	Rolled DE + glue	Rolled DE + sewing	Pressed
Costs				
Contact resistance				
Mechanical connection (stiffness/flexibility)				
Integrability				
Comfort				
complexity				
Fatigue strength				

Connection concepts							
Costs							
conductivity							
Mechanic flexibility							
Integrability							
comfort							
Connection to electronic							
Connection to DE							

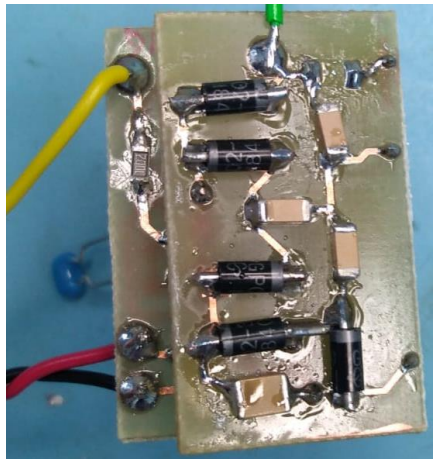
Connection concepts

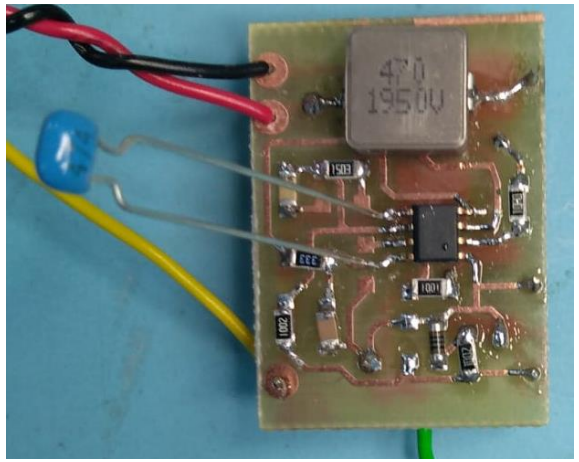




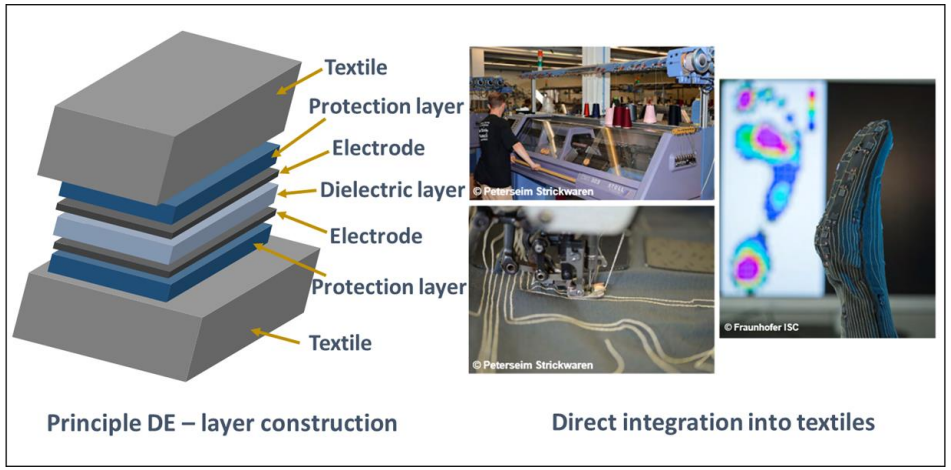
Smal electronic and textile integration

High voltage electronic

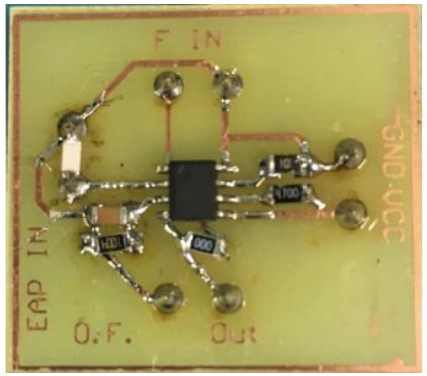


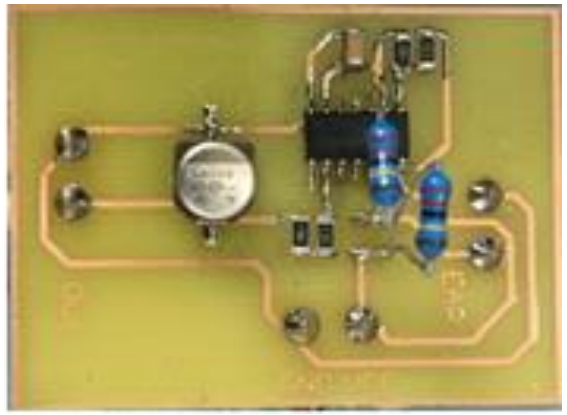


Integration into textiles

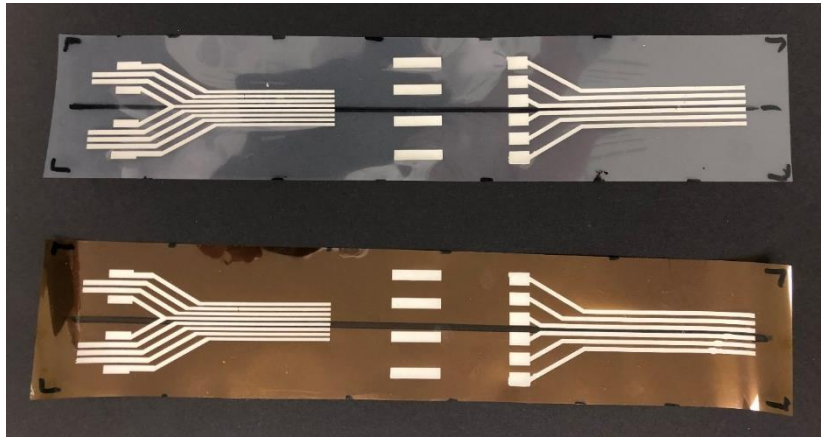


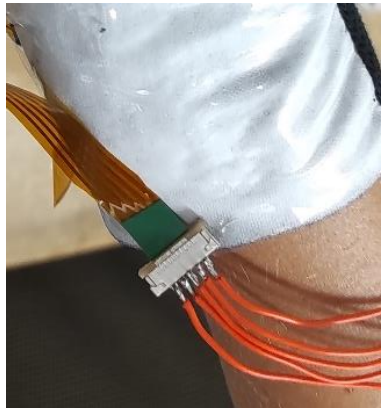
Capacitance measurement electronic





Connection to electronic





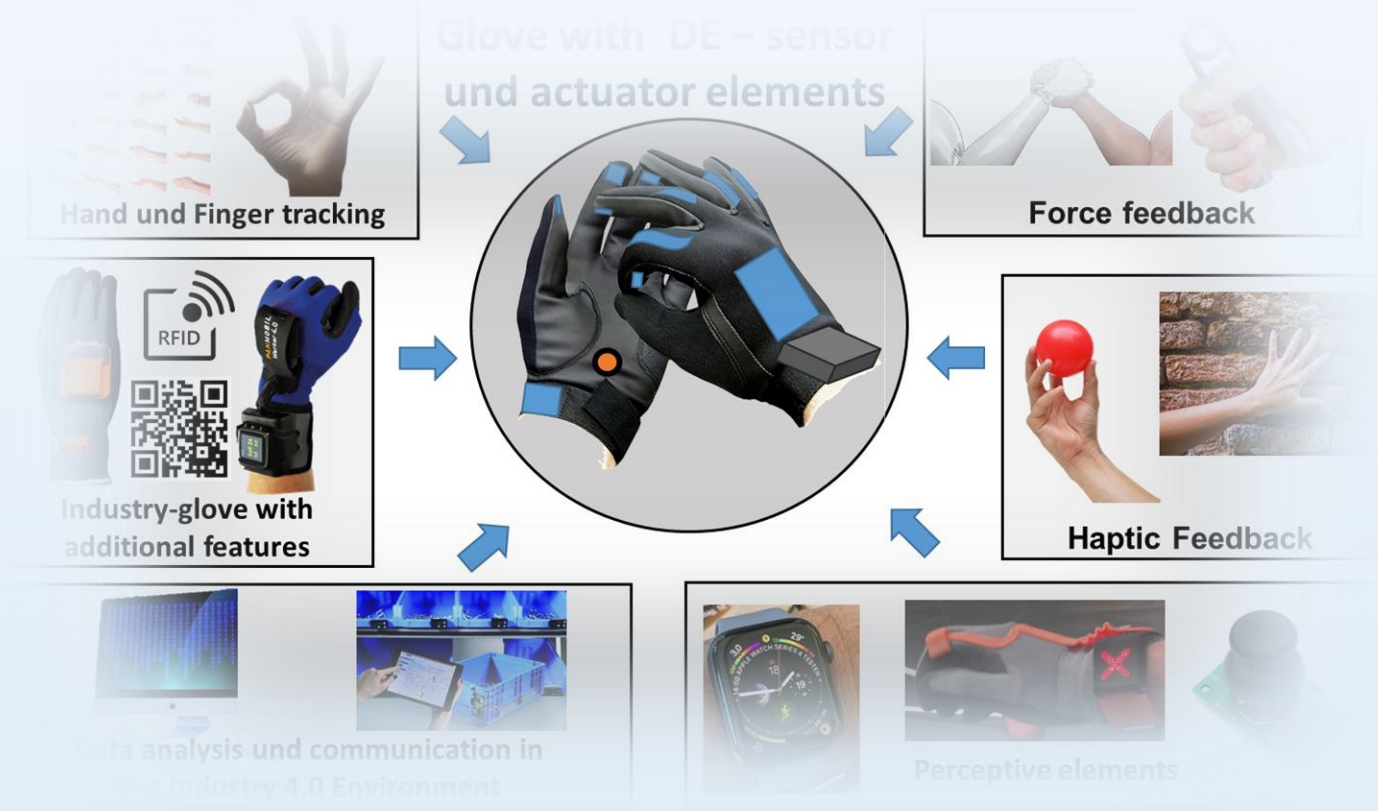
Structure of the assistance tool

- sensor
- actuator
- electronic
- integration

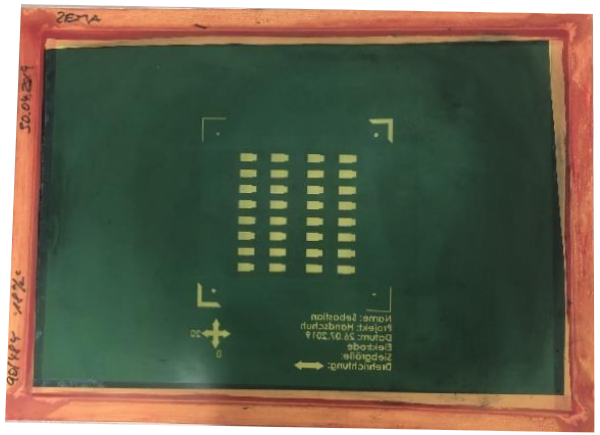
Prototype assembly

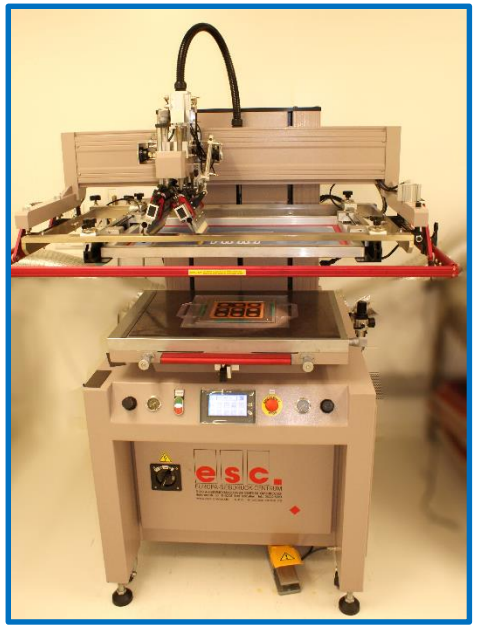
Prototype validation

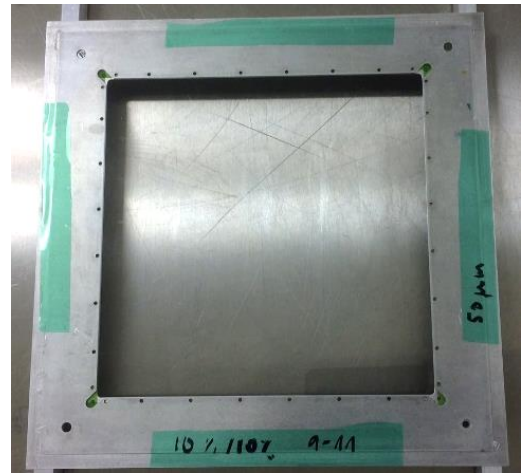
Summary and outlook

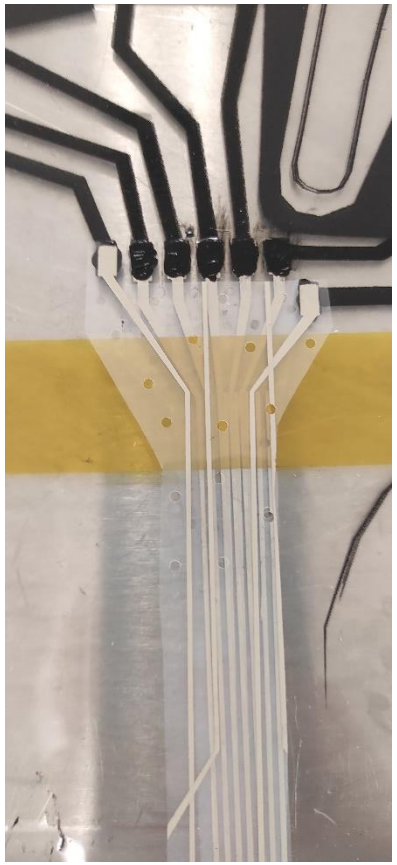


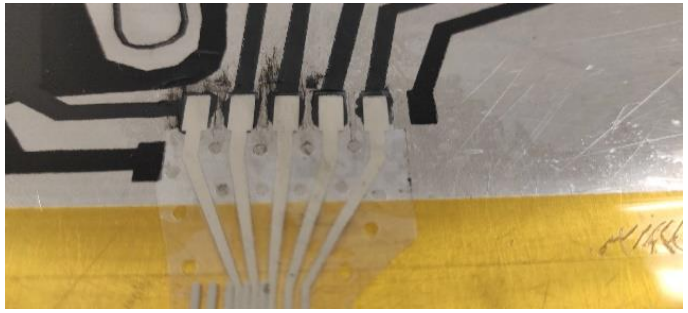
Printing the Electrodes



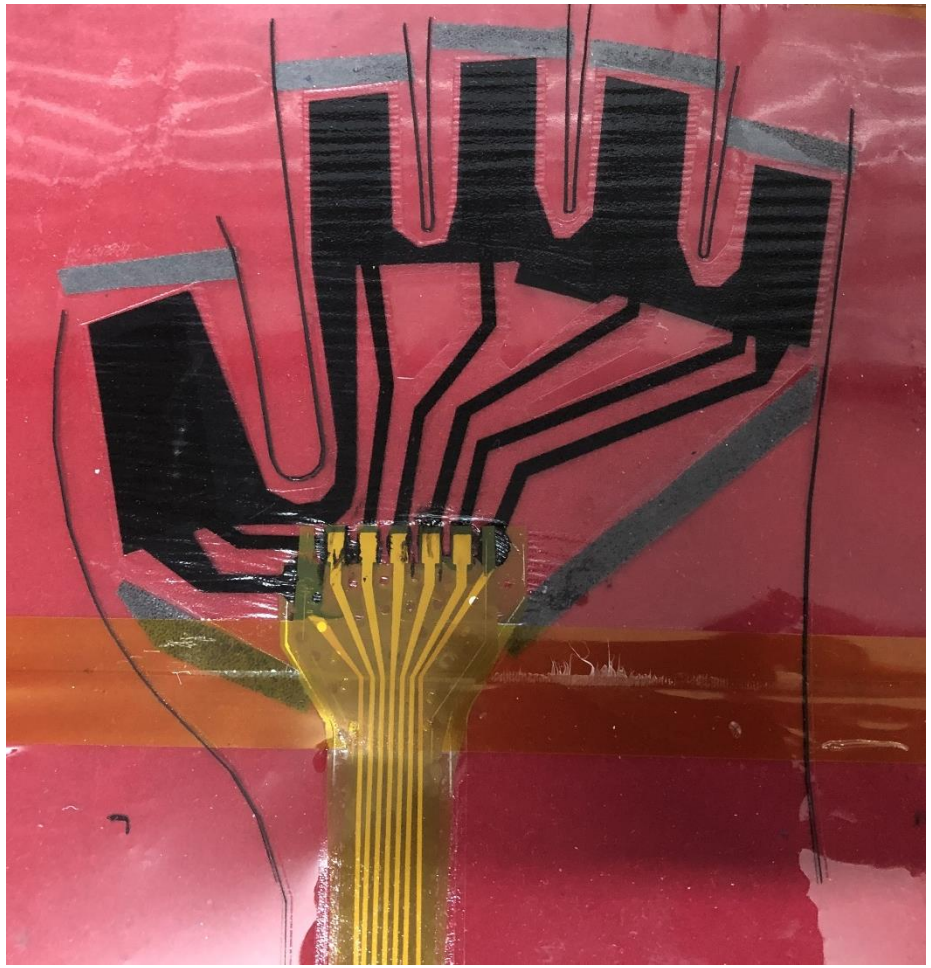








Silver printed conductor track glued onto the electrode



Screen-printed Protection layer
Textilstrips for sewing

Ironing textile strips onto the silicone

Sewing textile strips onto the Glove textile

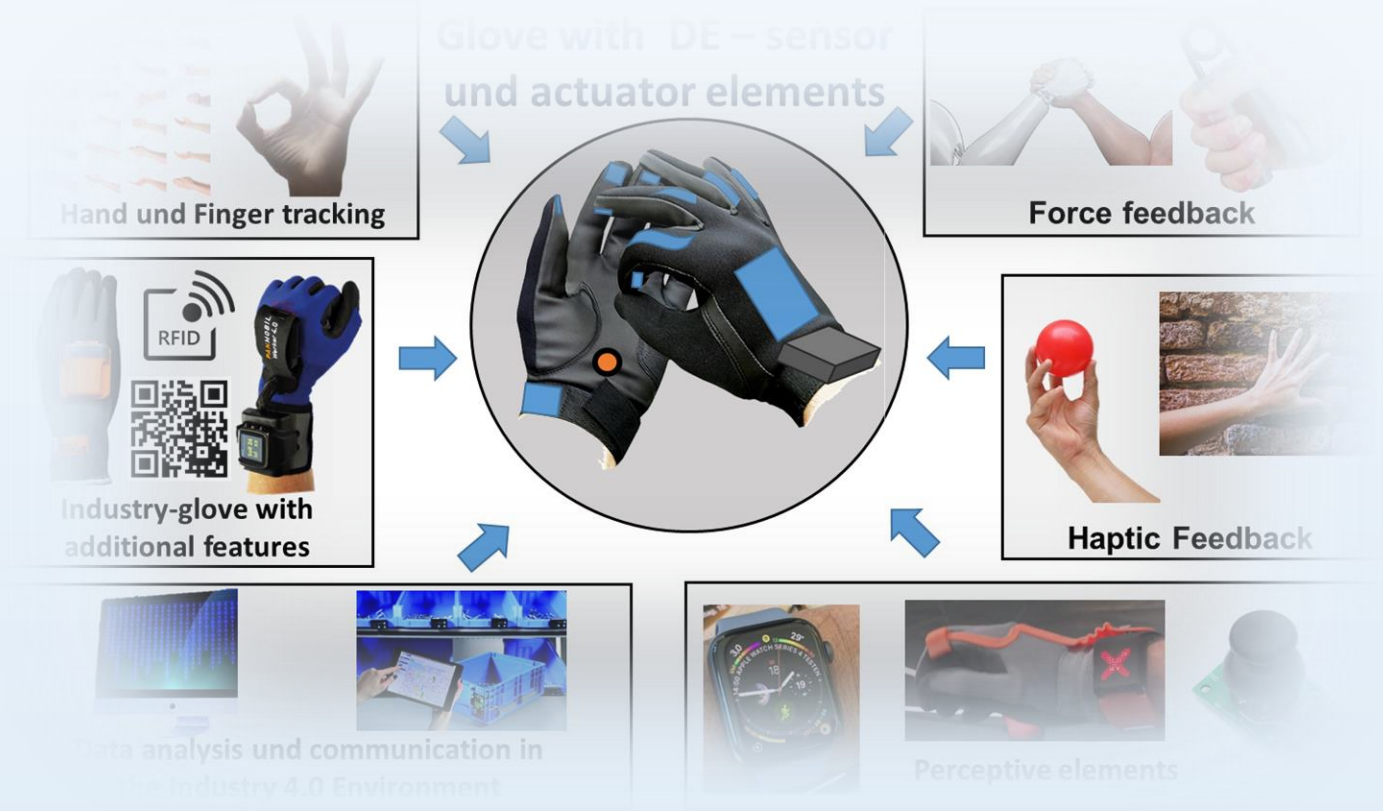
Cut out the glove pattern

Structure of the assistance tool
- sensor
- actuator
- electronic
- integration

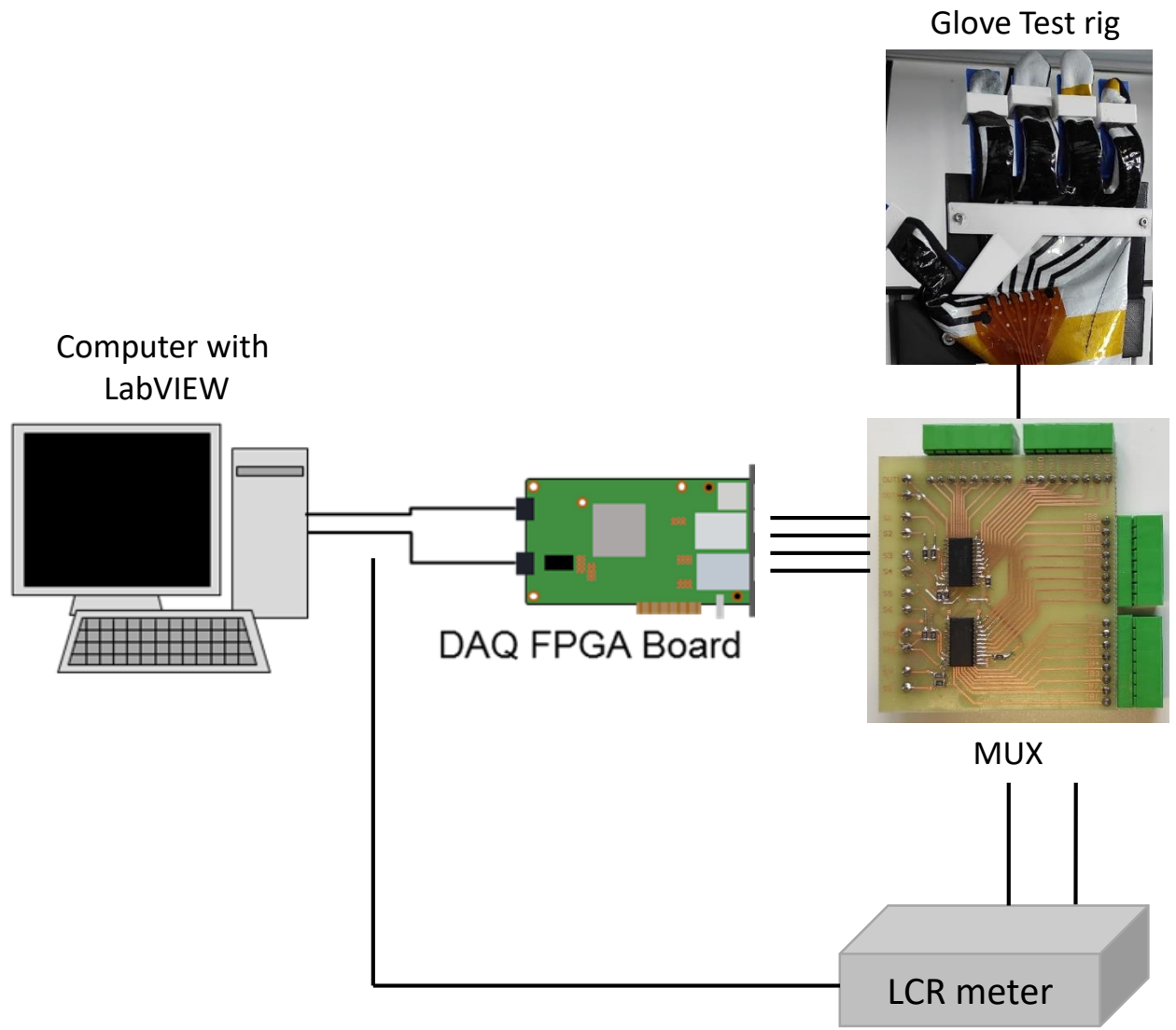
Prototype assembly

Prototype validation

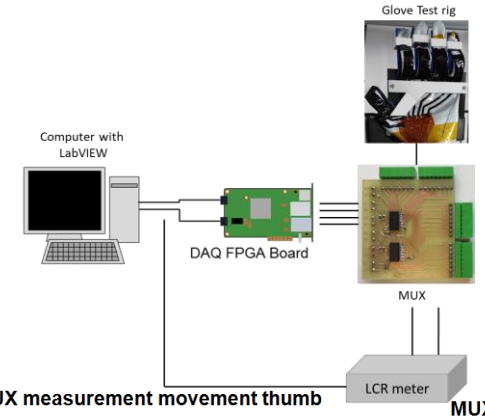
Summary and outlook



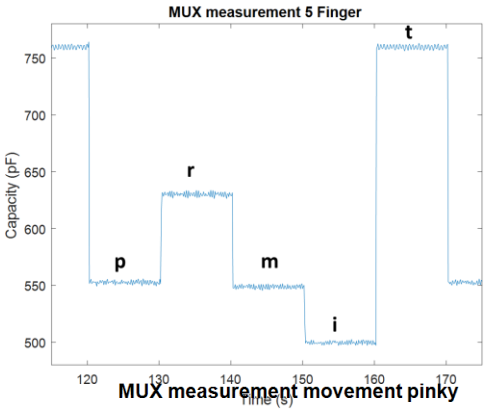
Prototype testing – measurement rig

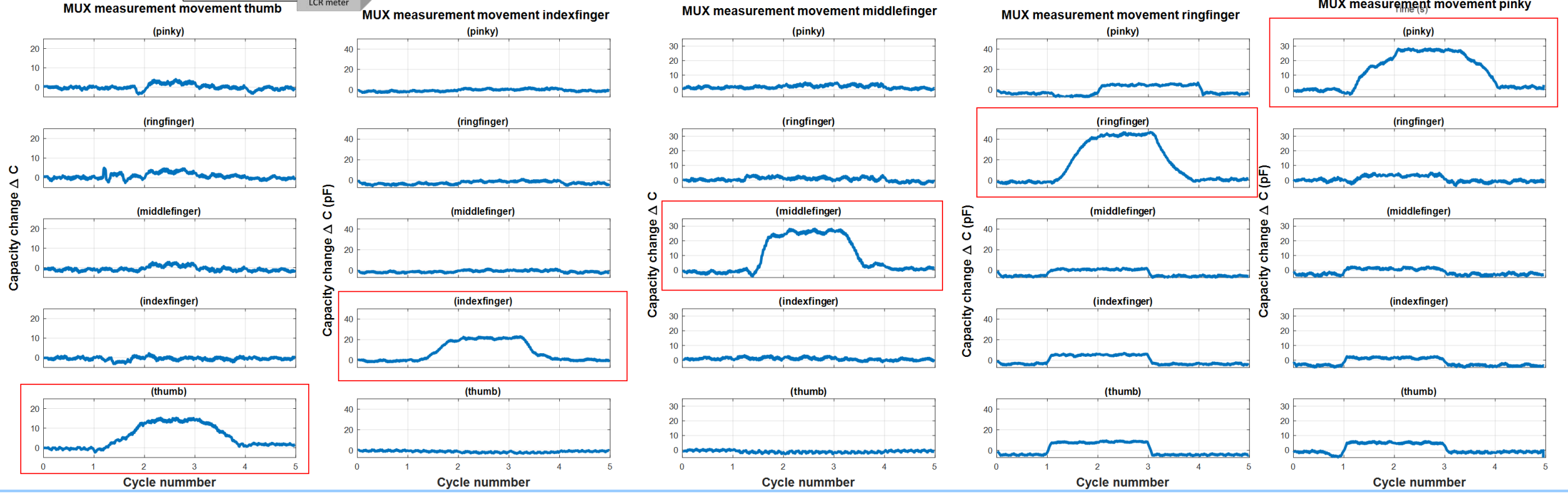


Prototype testing – measurement rig



Measuring of different fingers bending



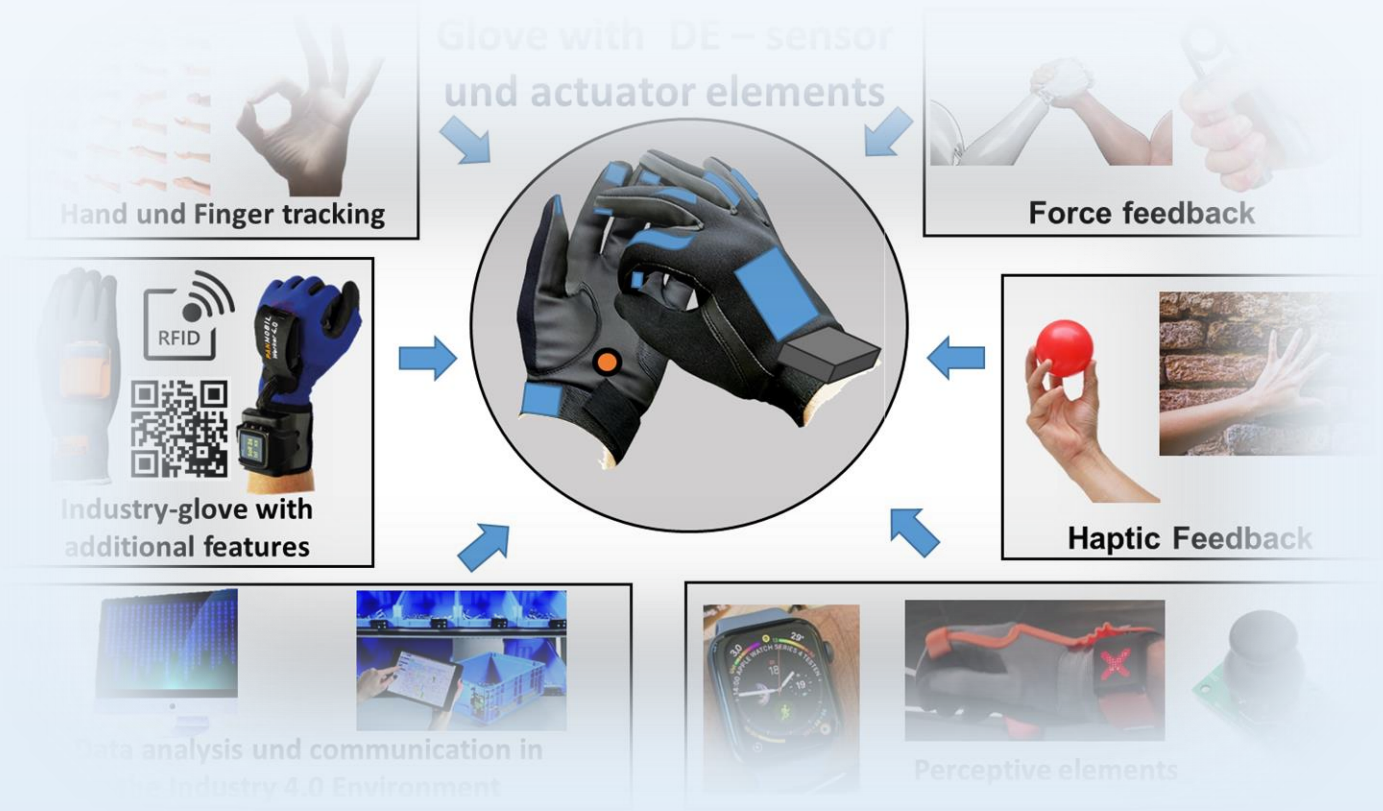


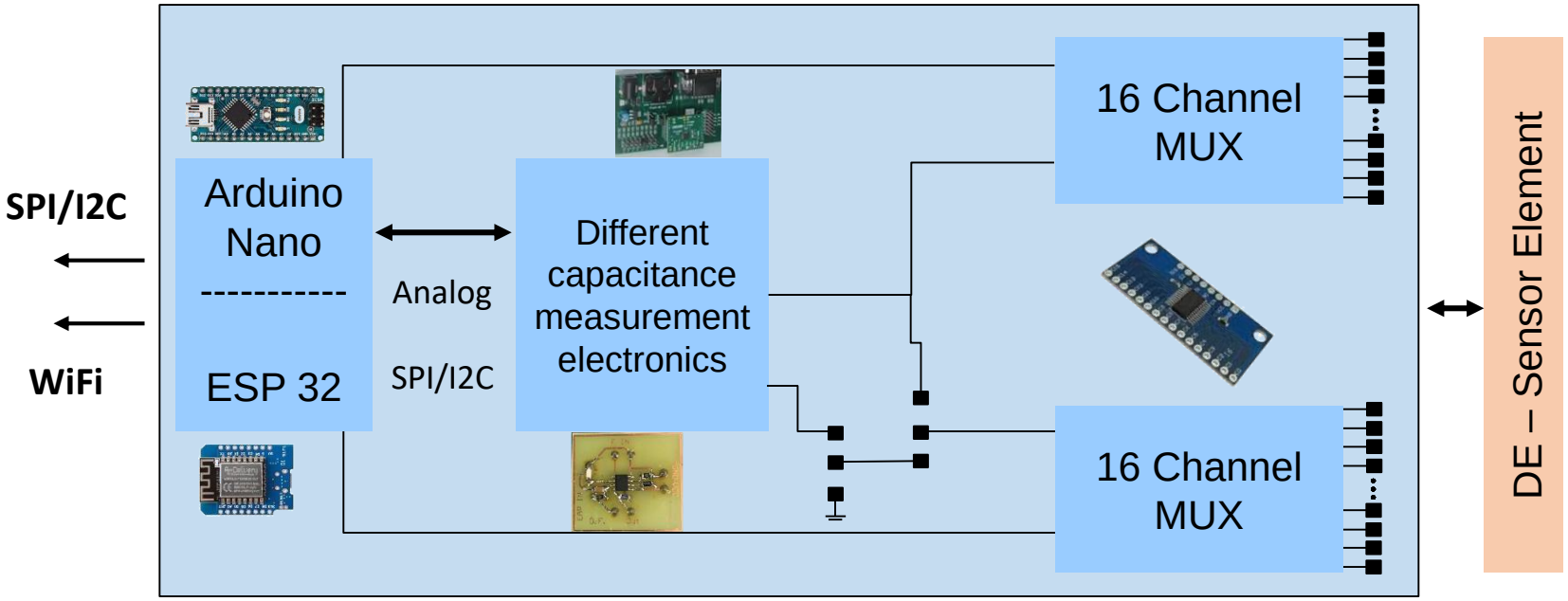
Structure of the assistance tool
- sensor
- actuator
- electronic
- integration

Prototype assembly

Prototype validation

Summary and outlook





Combination:

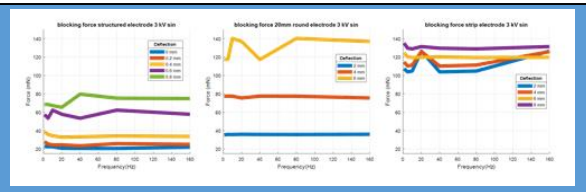
Glove with sensor and actuator elements

High voltage and capacitance measurement electronic

Circuit board

- 16 DE sensing differtially
- 32 DE sensing to Ground
- Flexible usage of different Microcontroller and Capacitance sensing IC‘s
- Potential usage of self developed NE555 circuit with additional IC for capacitance measurement

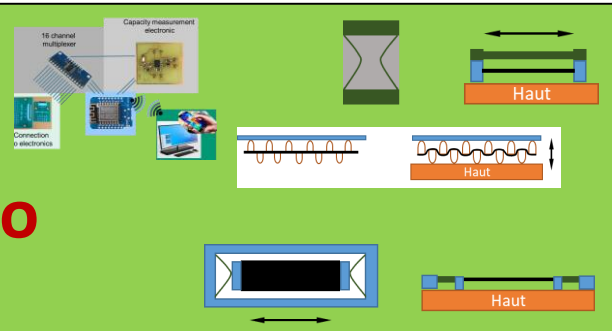
- Prototype assembly (5 sensor element)
- Measurements with multiplexed sensor glove
- Haptic feedback
  - compared working principles
- Strip DE Design



Summary

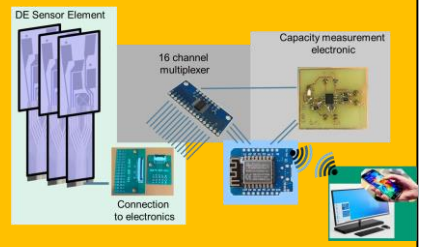
- Haptic feedback
  - Prototype manufacturing
- Haptic Feedback Prototype assembly (more Layer)
- Electronic development
  - Sensor circuit board
  - High voltage electronic

To Do



- Actuator development (additional elements)
- Multi sensor measurement
- Communication development
- Combination sensory and actuator electronic
- Miniaturized electronic board

Outlook



Thank you for your attention!

ME SAAR
DIE METALL + ELEKTROINDUSTRIE

IHK Saarland

ZeMA

PROMOTIONS-KOLLEG DIGITALISIERUNG DER PRODUKTION