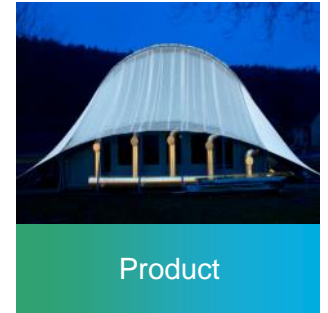
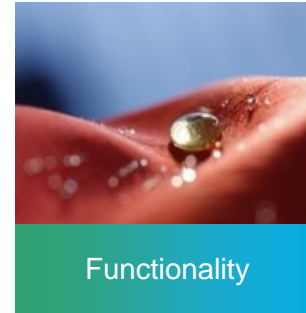
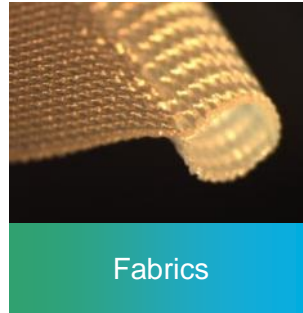
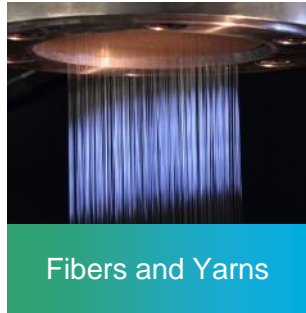


The title 'Sensor Yarns in biomedical and technical applications' is centered in a white, sans-serif font. It is overlaid on a horizontal band that features a green and teal color scheme with various mesh and fabric textures, including a fine grid, a larger diamond mesh, and a complex woven pattern.

Bastian Baesch, Carsten Linti

Textile Vertical Integration

FROM MOLECULES TO PRODUCTS



Europe's Largest Textile Research Center

Key Figures 2021



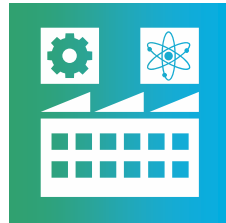
Employees

approx. **250**



Turnover

13 m € public
15 m € industry



Area

25,000 m²



Research

159 public
589 industry



Partners

1196 enterprises
80 % SME



Services

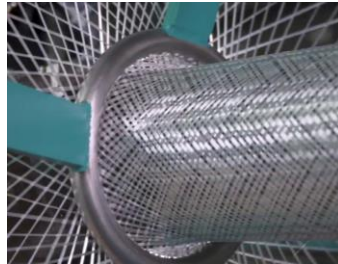
109 test customers
5 small batch series

Textile Future

RESEARCH FIELDS



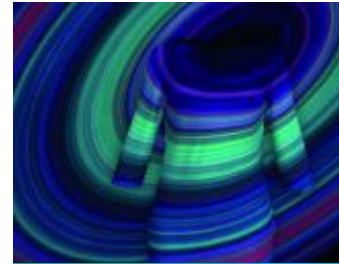
New Materials



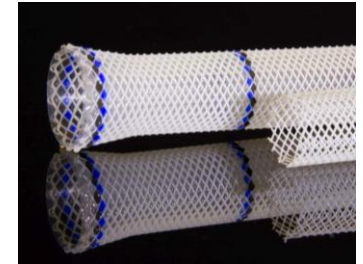
Lightweight Construction



Sustainability

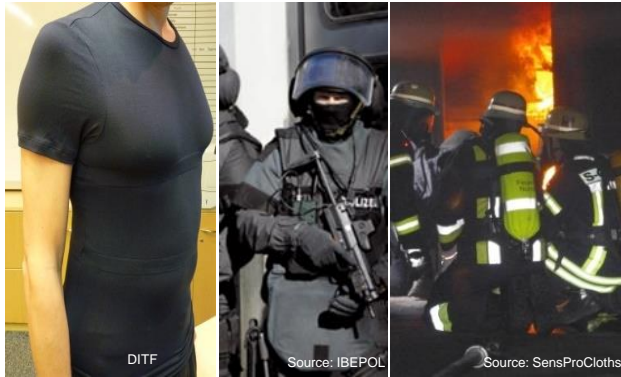


Digitalization



Health

E-Textiles for Health Care and Wellbeing



Today

Sensory shirts for monitoring vital parameters to support and protect persons in mental and physical stress



Future
Location-independent
emergency medical monitoring

Vision

Garment-integrated disaster recovery,
e.g. automated external defibrillator

B. Baesch, C. Linti - Sensor yarns in biomedical and technical applications - ET Conference, Orlando (FL), 2023



(Smart) Textiles for Health in all Ages



&



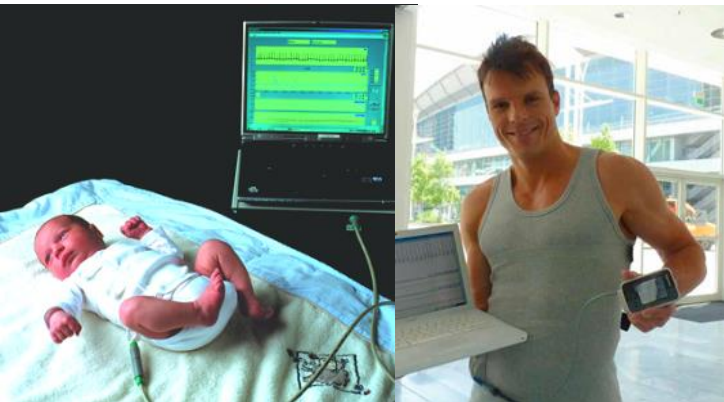
&



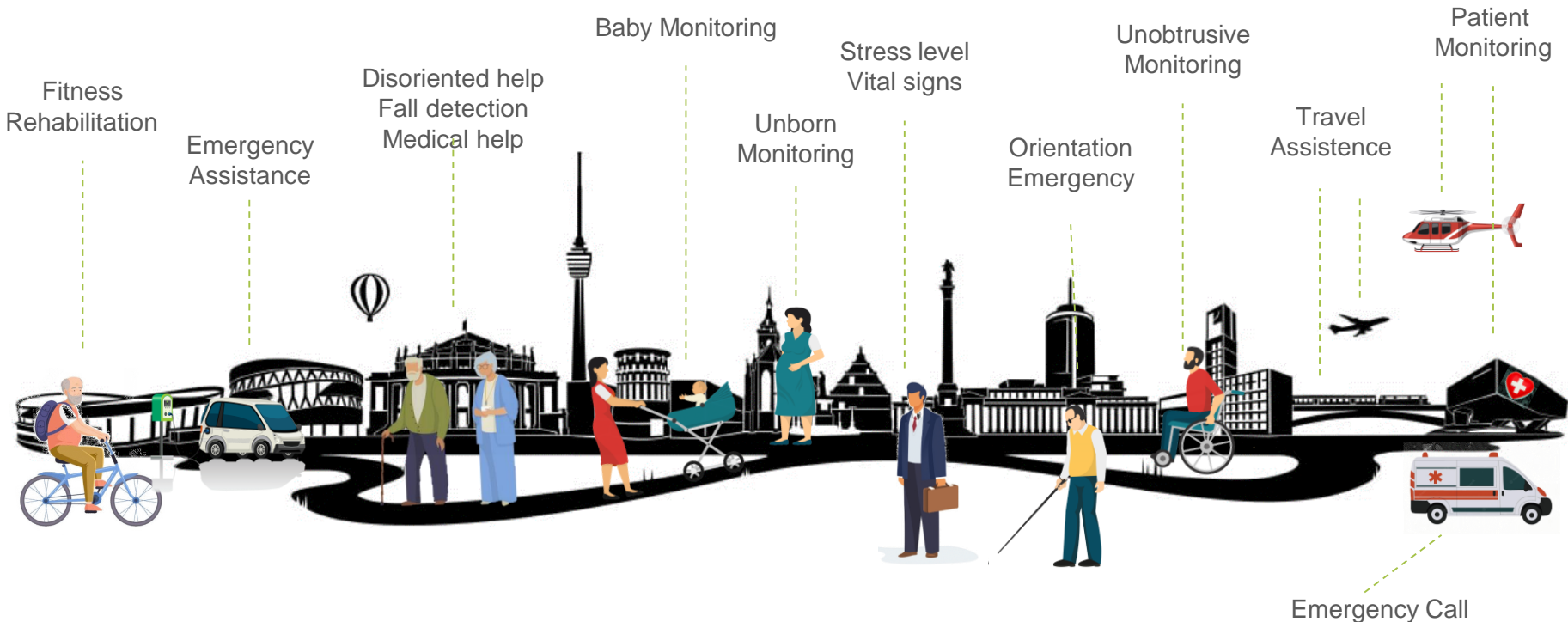
Textiles cover (almost) the
complete
human body

Textiles are common to
all
people in society

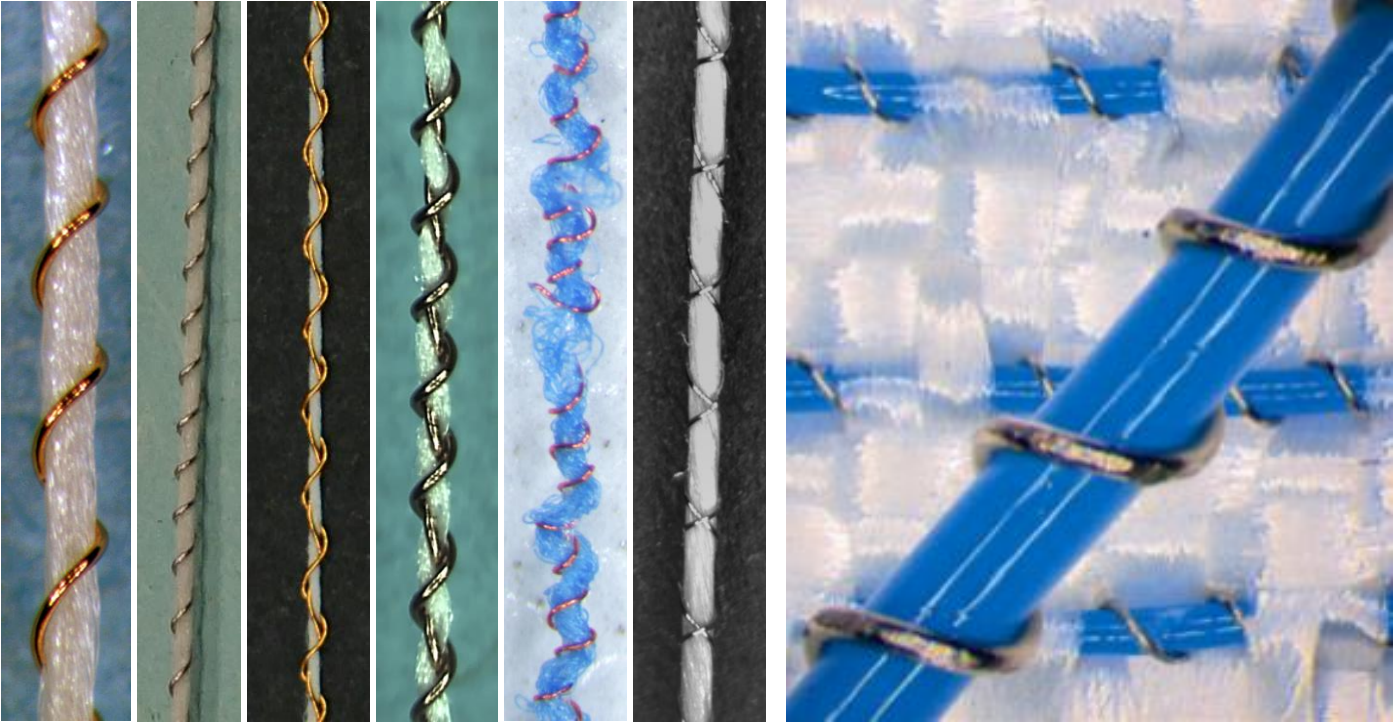
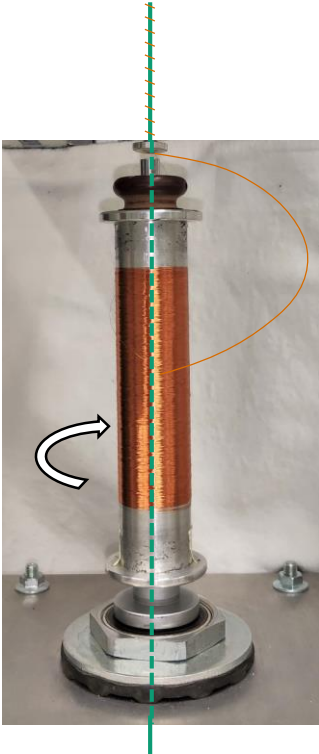
Textiles are around us
all time
in our daily lives



Smart Textiles Supporting Health Care in Everyday Life



Yarn Wrapping Technology



Wrapped Sensor Yarns - Possibilities



- Textile usage and processing properties are adaptable to almost all yarn and textile materials (Lycra, CO, PES, glass, carbon, and others.)
- Adaptable electrical properties by adapting the wire material (Cu, Ag, Au, Pt, NiCr, etc.)
- The use of several conductors in one yarn is possible
- The use of several insulated conductors is possible by the use of enameled wire
- If necessary, additional protective or functional wraps are possible (for example iron-on conductive yarn by using a fusible component in the winding)
- Very low electrical resistances possible (<5 Ohm/m for 167 dtex PES core yarn)

Twisting and Wrapping Machines at DITF

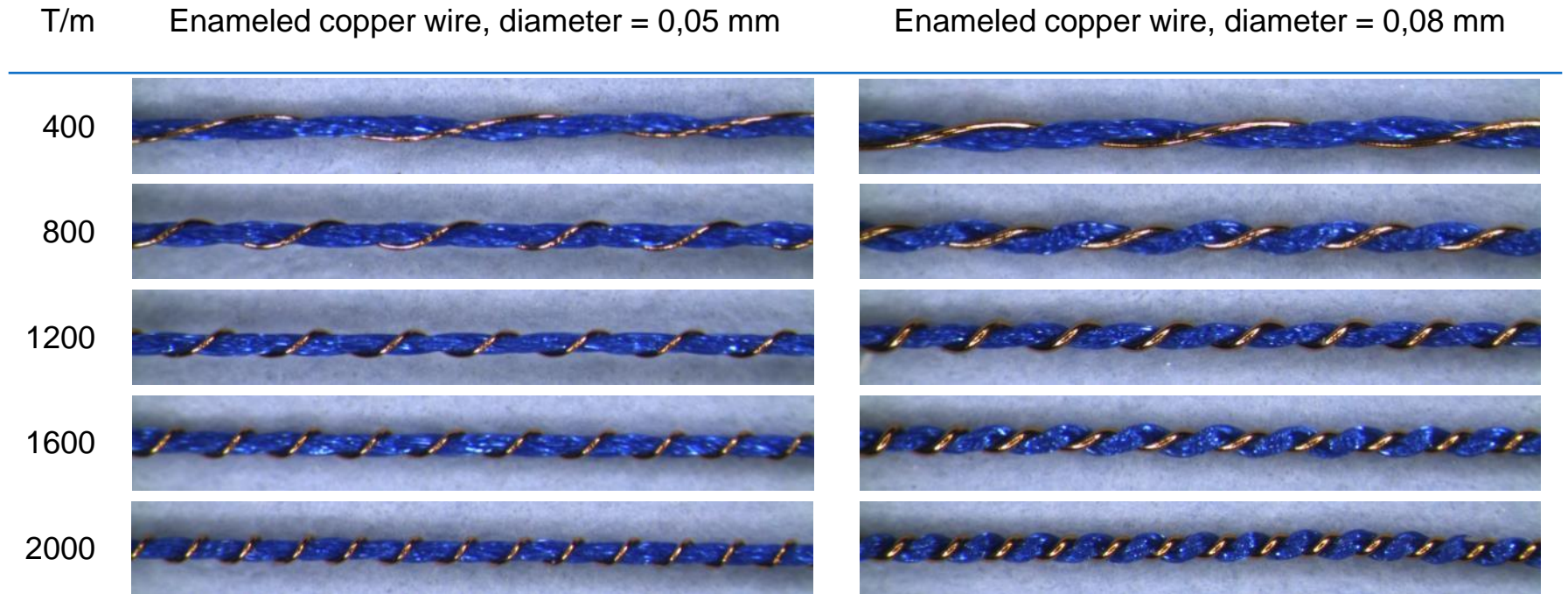
Two (small) industrial scale and two self-build research machines are available at DITF

- 4 Hollow spindles
- 1 and 2-fold wrapping in one process
- 1-fold wrapping:
4 spooling positions
- 2-fold wrapping:
2 spooling positions
- Precision winding (or other)
- wrapping spindle speed:
0,5 - 24000 RPM
- Developed together with industrial Partner JBF



- Less configuration options
- 1-fold wrapping in one process
- Wild winding (right) or parallel winding (left)
- Spindle speed max.
14000 RPM
- Turns per meter Yarn:
2000 T/m
- Spooling speed
7-200 m/min

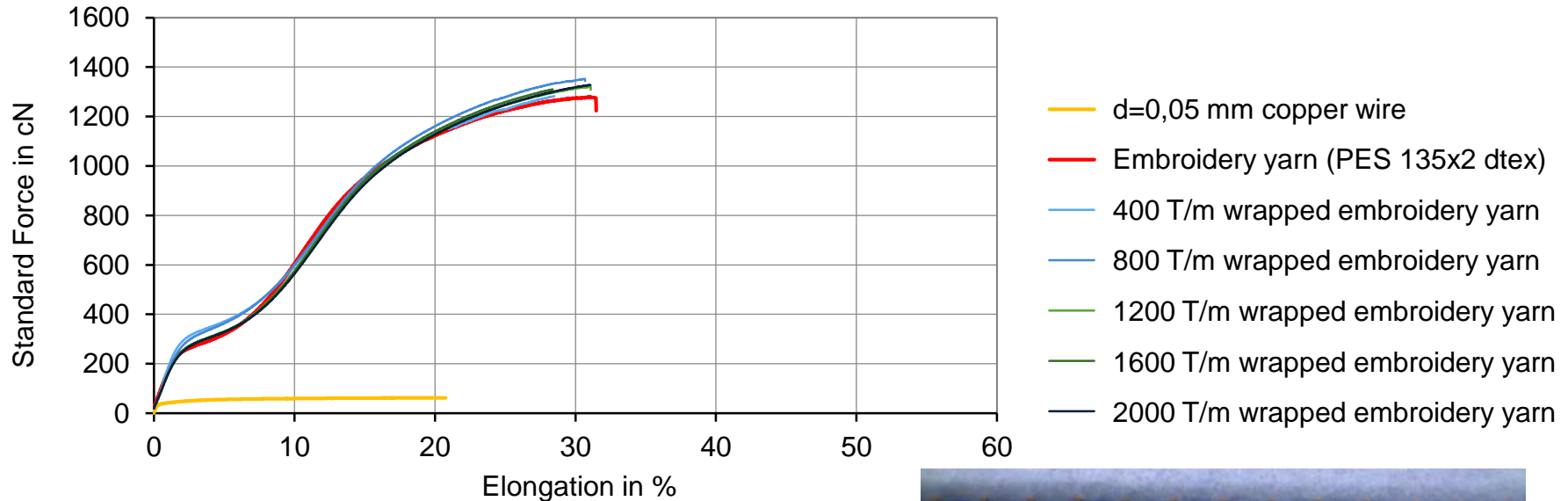
Force-strain-behavior of wrapped sensor yarns



Core: Embroidery yarn Madeira Polyneon No40 (PES 135x2 dtex)

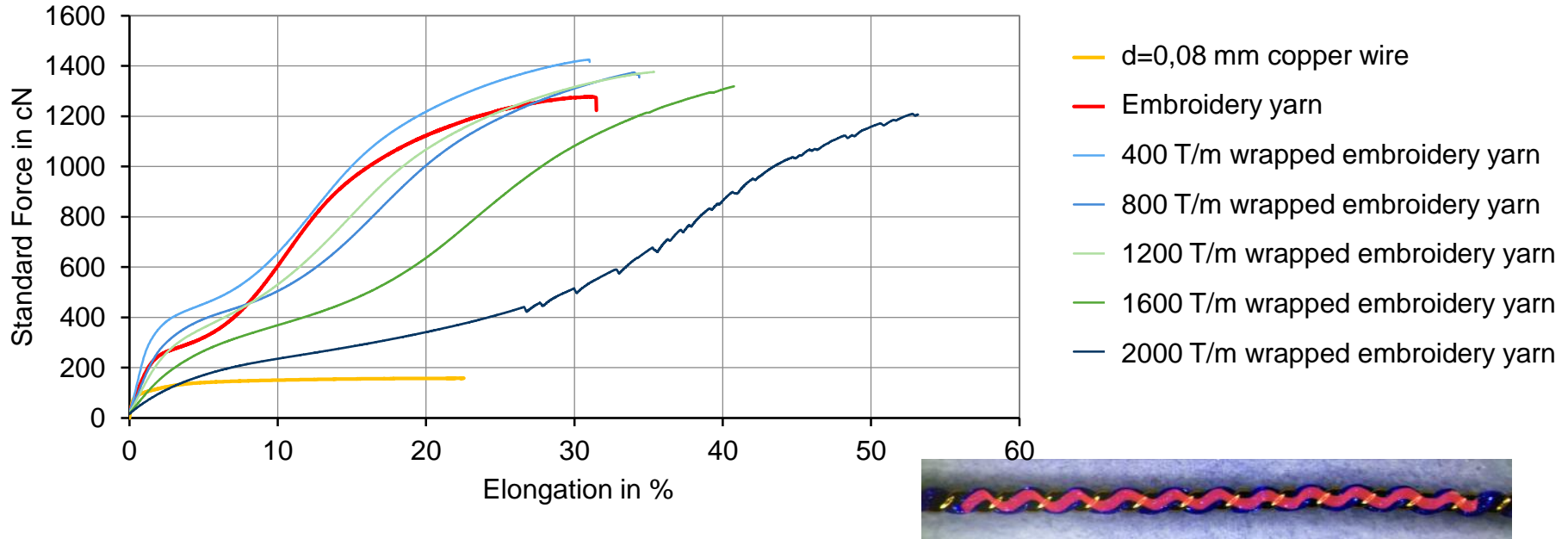
Force-elongation-behavior of wrapped sensor yarns

Force-elongation behavior of $d = 0,05$ mm copper wire, embroidery yarn and several copper wire wrapped embroidery yarns (wire diameter $d=0,05$ mm)

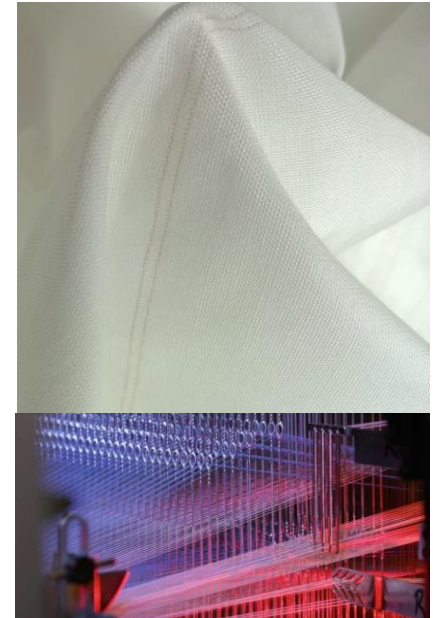
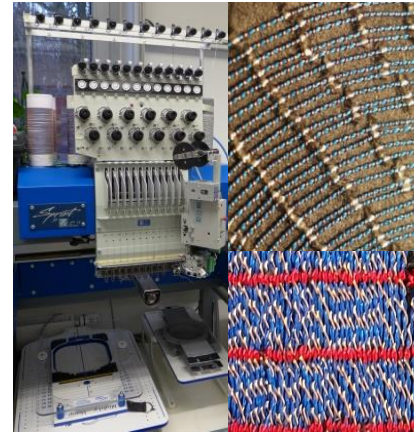
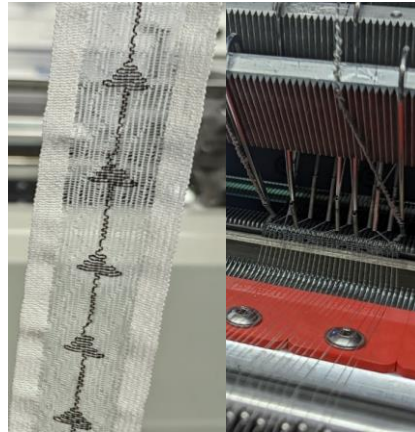
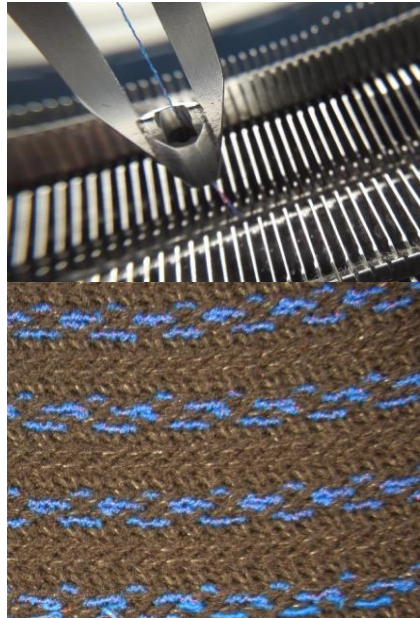


Force-elongation-behavior of wrapped sensor yarns

Force-elongation behavior of $d = 0,08$ mm copper wire, embroidery yarn and several copper wire wrapped embroidery yarns (wire diameter $d=0,08$ mm)



Integration of wrapped sensor yarns into textile structures

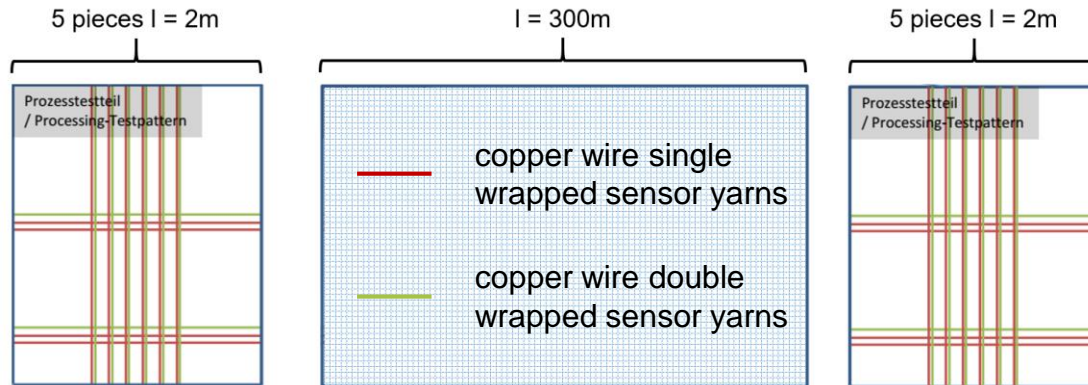


Conventional textile production processes can be used at conventional production speeds.

Industrial weaving trials with wrapped sensor yarns

Processes:

1. Weaving (ambient conditions, rapier loom, canvas)
2. Washing (95 °C / 203 °F, wide washer)
3. Drying (110 °C / 230 °F, stenter frame)
4. Dyeing (120 °C / 248 °F, strand dyeing machine)
5. Heat setting (180 °C / 356 °F, stenter frame)
6. Thermocalandering (170 °C / 338 °F, transfer calander)
7. Pleating (140 °C / 284 °F, pleating machine)



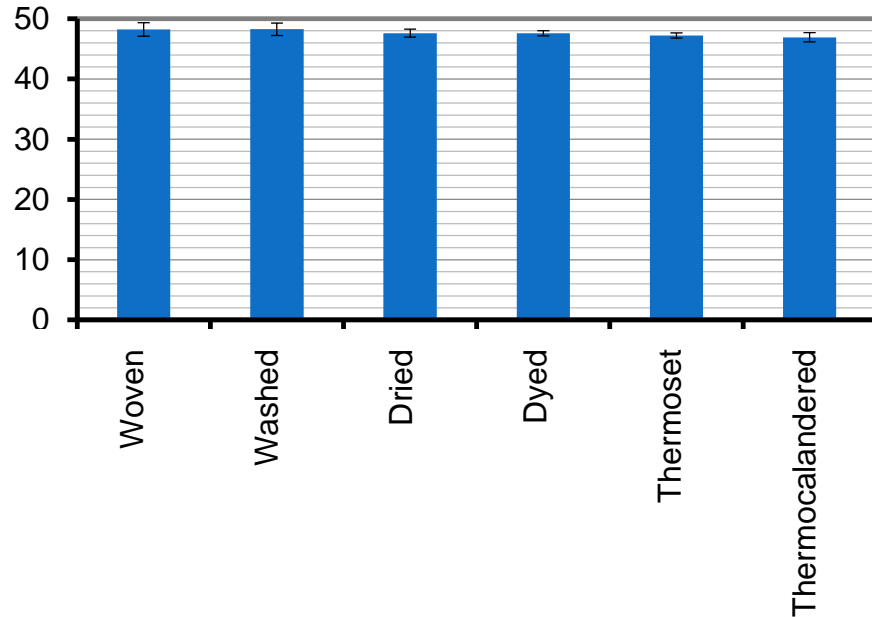
sensor yarn core:
same as the fabric consists of

copper wire:
enameled, diameter: 50 µm

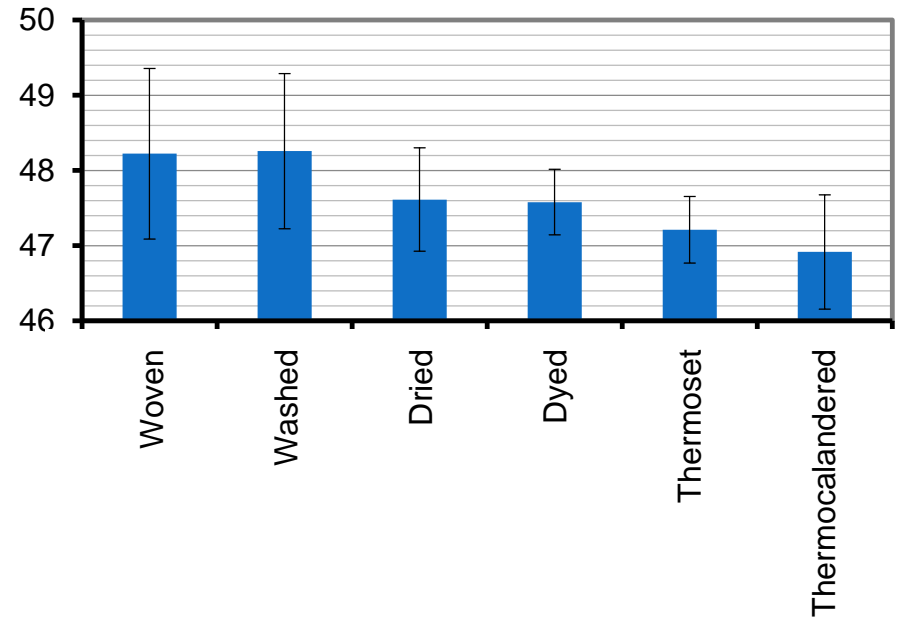
processing speeds:
same as without sensor yarns

Industrial weaving trials with wrapped sensor yarns

Contact resistance through single wrapped sensor yarns in Ohm



Contact resistance through single wrapped sensor yarns in Ohm



Industrial weaving trials with wrapped sensor yarns

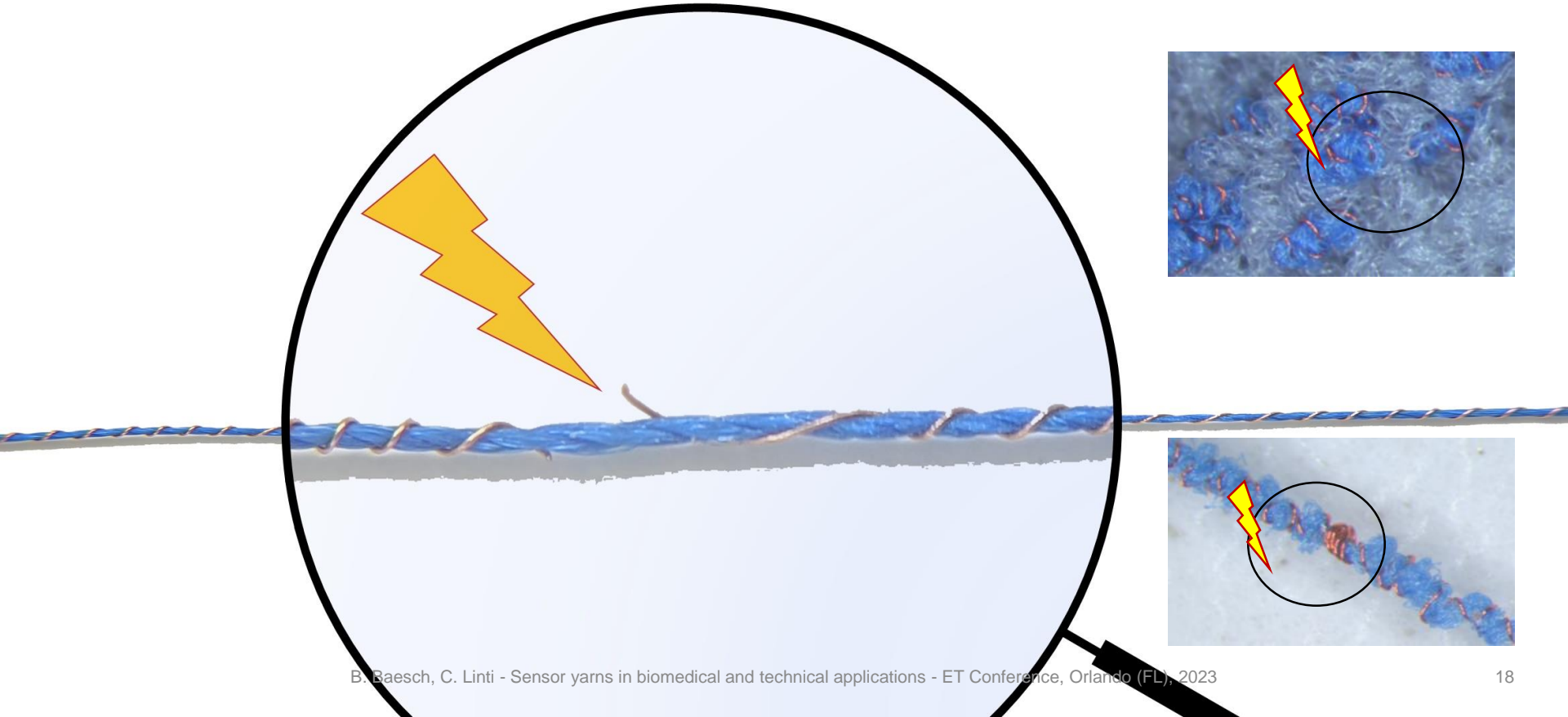
Results of a continuity test of weft yarns after several process steps:
(enameled wires were stripped manually)

#	Process	Single copper wrapped			Double copper wrapped (inner wire)			Double copper wrapped (outer wire)		
		tested	o.k.	[% o.k.]	tested	o.k.	[% o.k.]	tested	o.k.	[% o.k.]
1	Weaving	20	20	100,0%	11	11	100,0%	11	11	100,0%
2	Washing	14	14	100,0%	5	5	100,0%	5	5	100,0%
3	Drying	16	16	100,0%	7	7	100,0%	7	7	100,0%
4	Dyeing	14	14	100,0%	5	5	100,0%	5	5	100,0%
5	Heat setting	16	16	100,0%	7	7	100,0%	7	6	85,7%
6	Thermo calandering	16	16	100,0%	4	4	100,0%	4	4	100,0%
Σ		96	96	100,0%	39	39	100,0%	39	38	97,4%

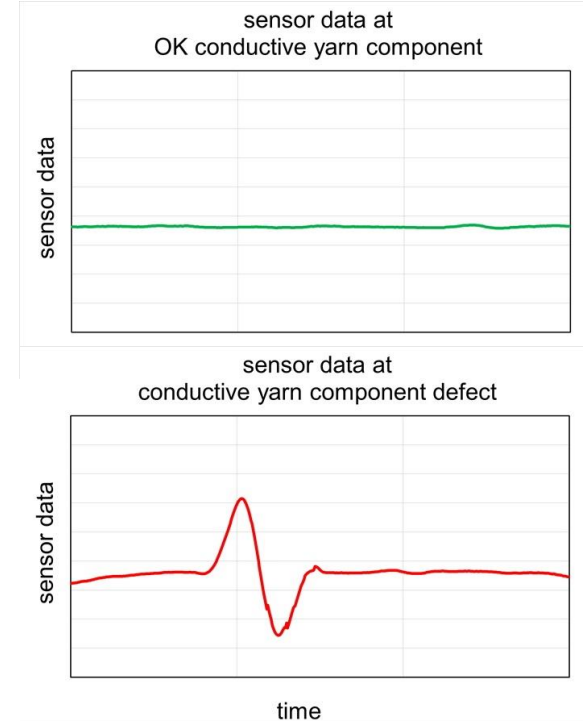


Results in the warp are similar, all single wound pleated sensor yarns were intact

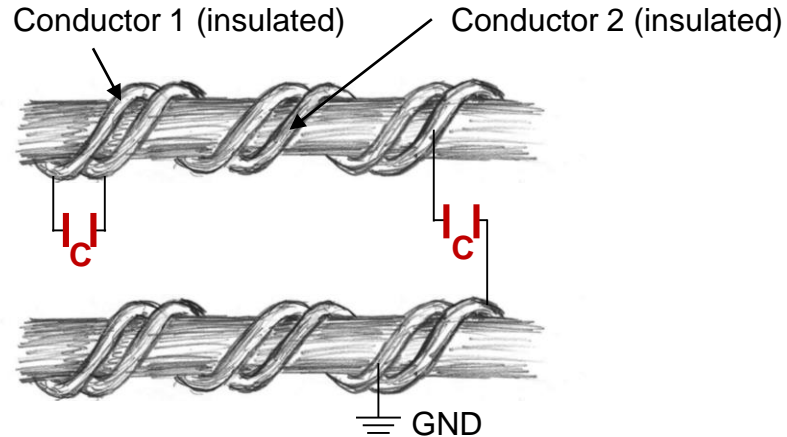
Conductive or sensor function can be faulty without changing the mechanical behavior



Contactless Sensor with new measurement principle



Wrapped Sensor Yarns – Possible Textile Sensor Applications



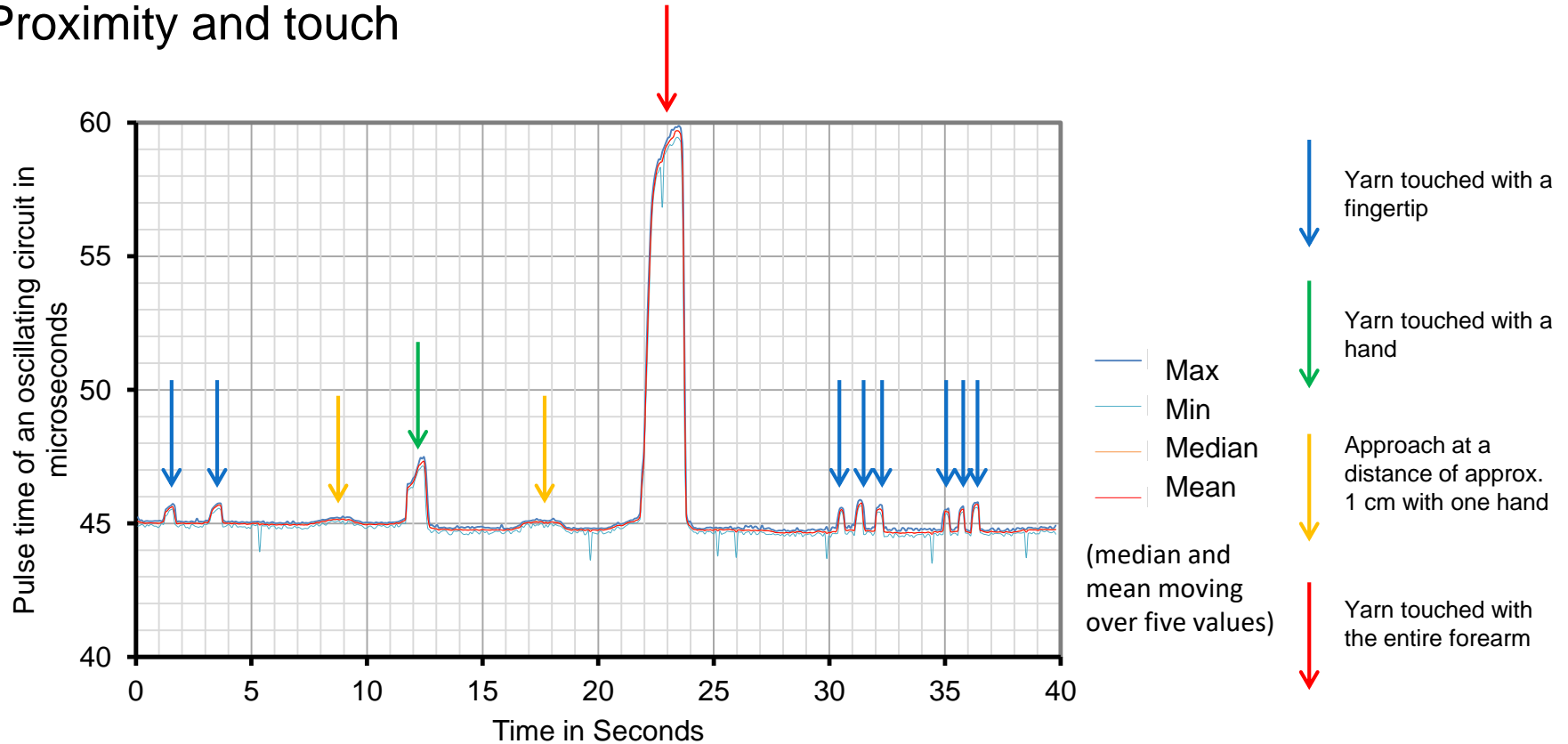
Insulated conductors form a capacitor with a capacitance C , which value depends on:

- The geometry of the two conductors,
- The permittivity of the surrounding materials

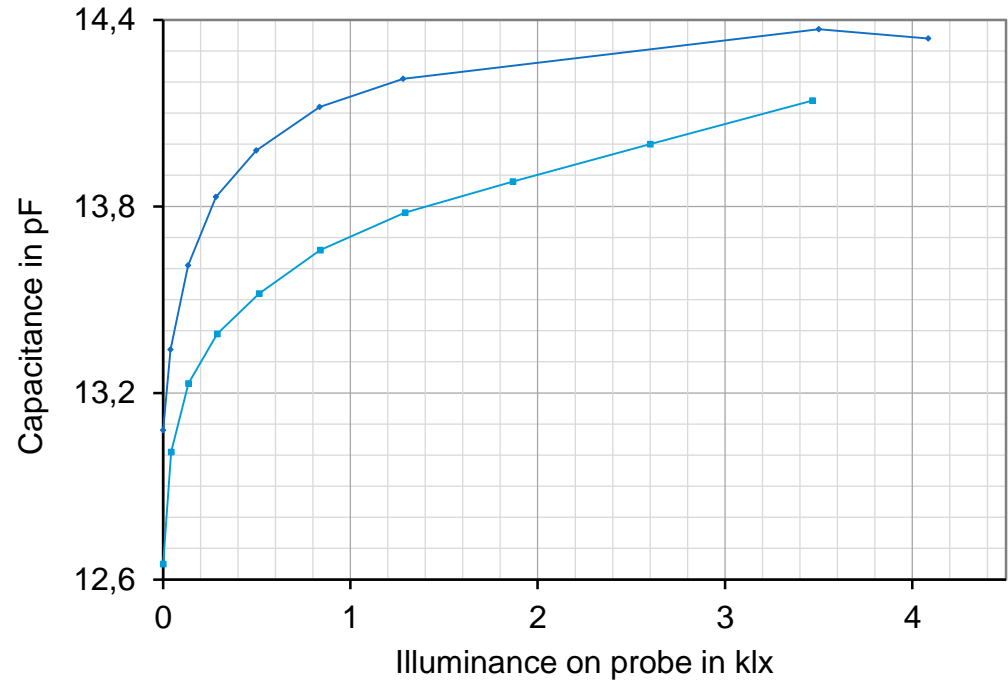
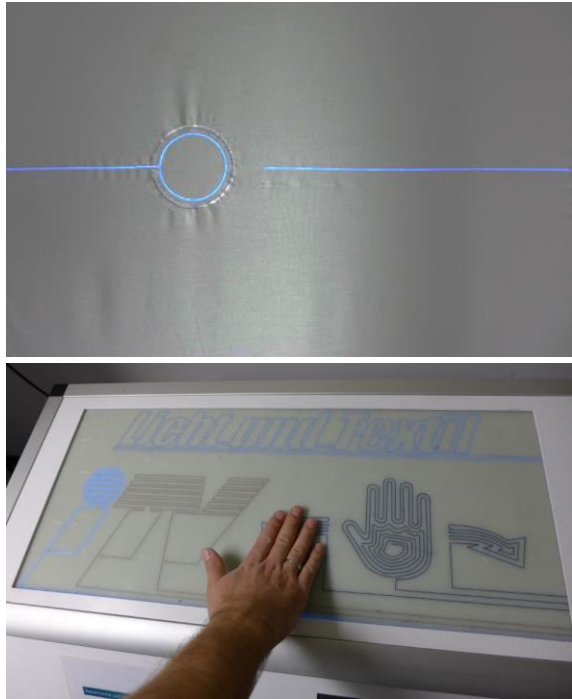
Single Point Connection is possible



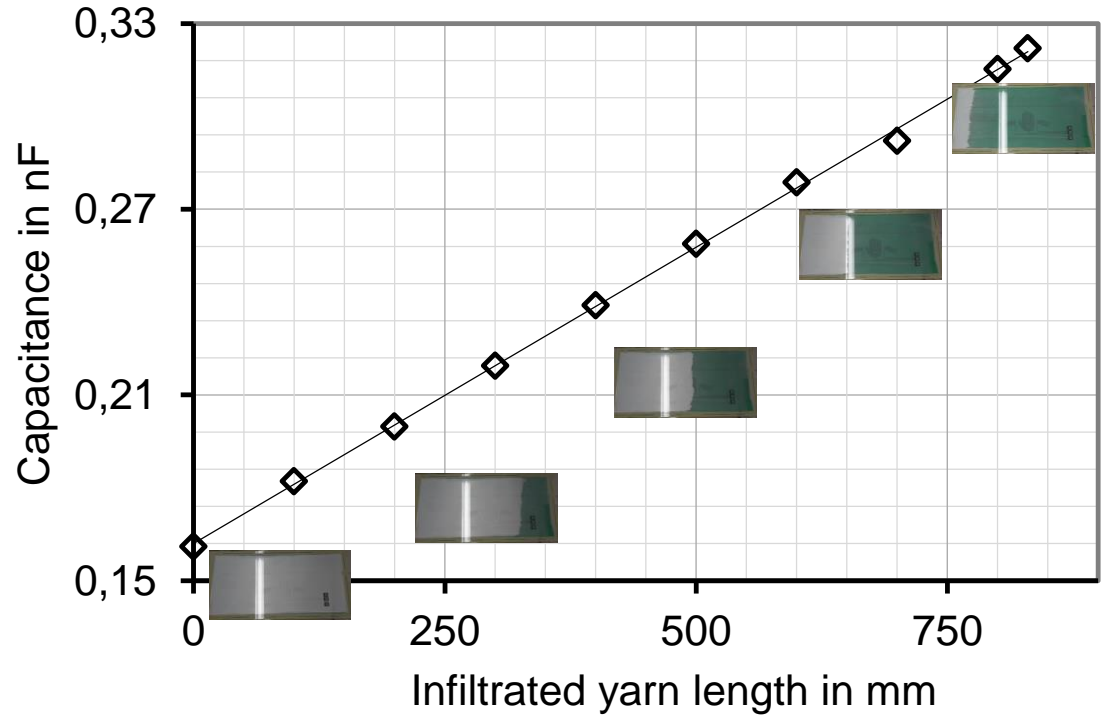
Proximity and touch



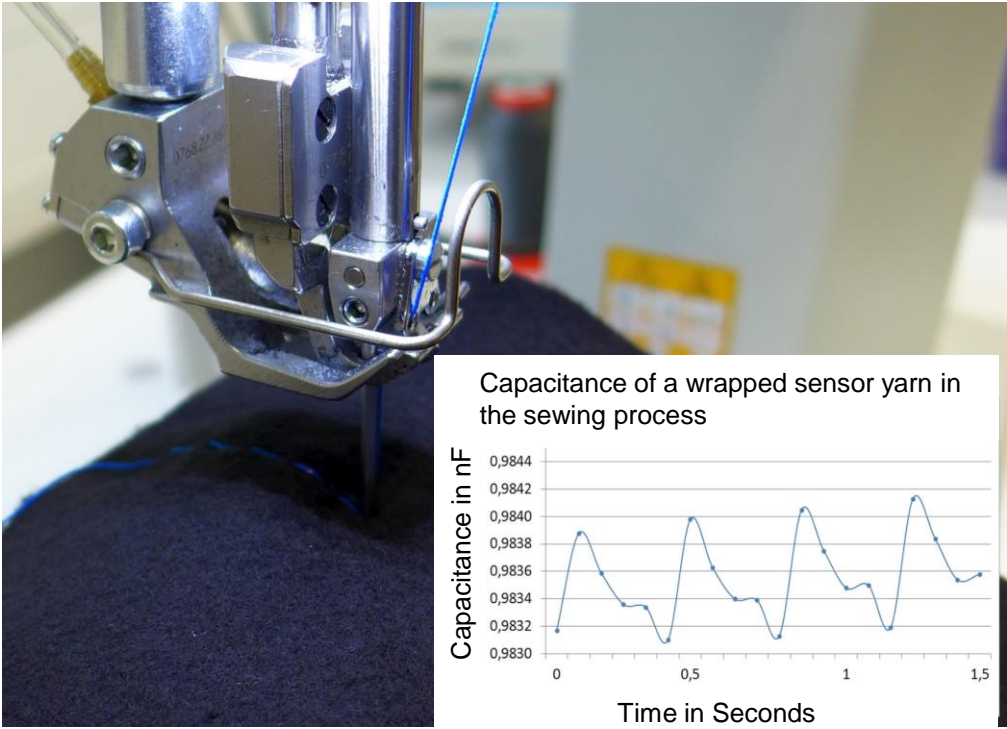
Electroluminescent and light-sensor textiles



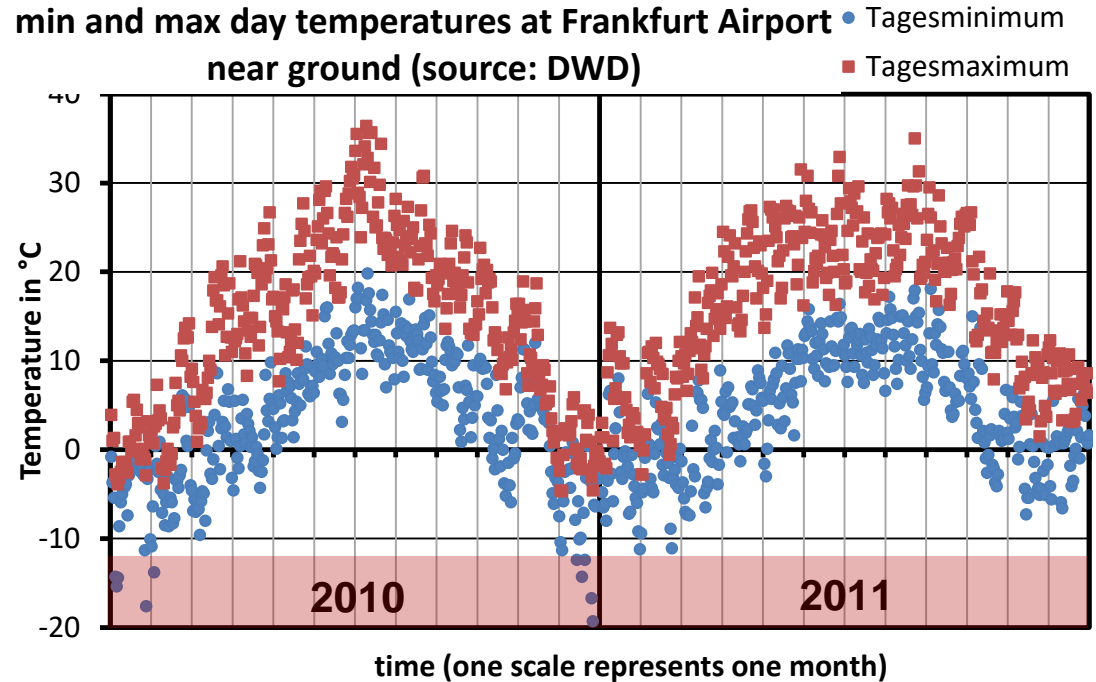
Quality monitoring of processes



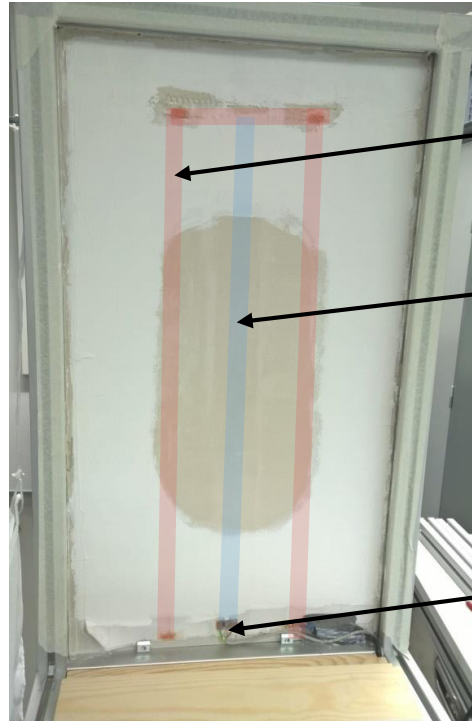
Quality monitoring of processes



Humidity - application example: mold prevention



Humidity - application example: mold prevention



Textile heating structure

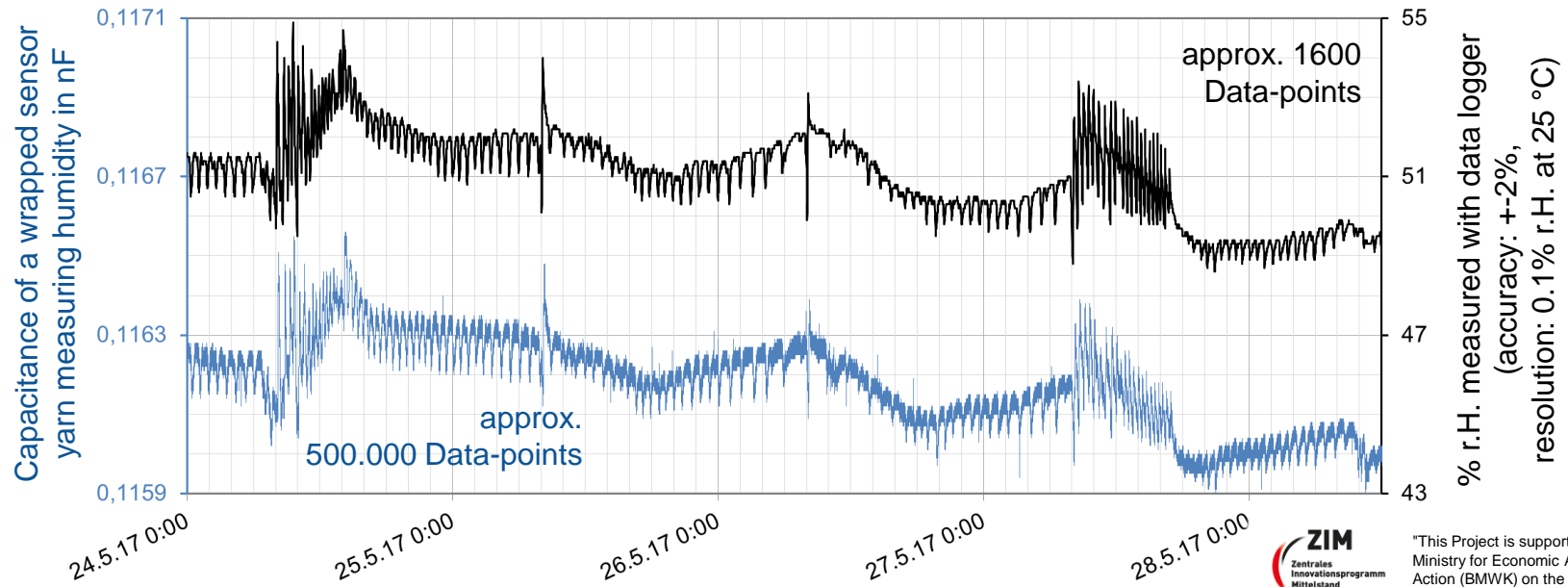
Textile measuring structure

signal processing integrated inside the skirting board



Humidity - application example: mold prevention

Comparison of the capacity of a wrapped sensor yarn with the measured relative humidity (r.H.) of a data logger

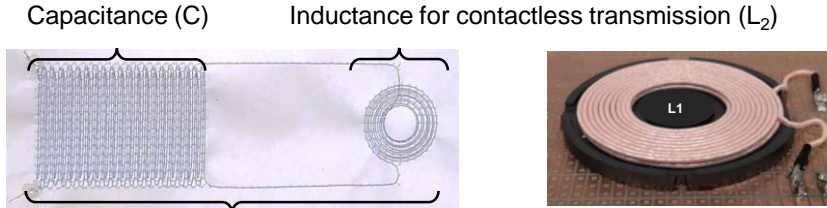
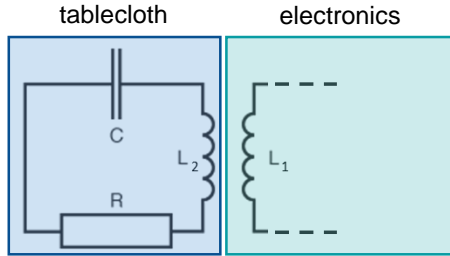


"This Project is supported by the Federal Ministry for Economic Affairs and Climate Action (BMWK) on the basis of a decision by the German Bundestag."

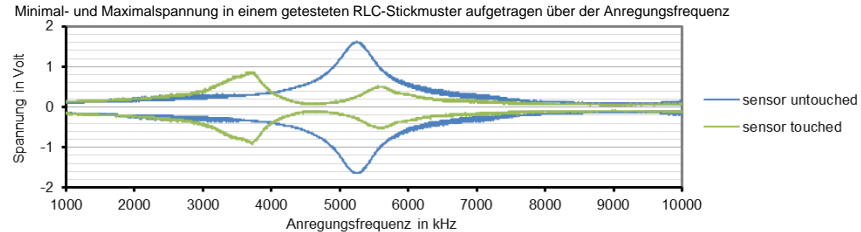
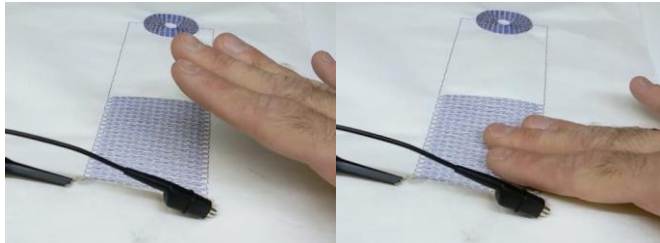
Application example: Contactless control via tablecloths

Wireless short-distance transmission of measured values from a sensor textile to conventional electronics without the need for additional electrical components or energy sources in the textile.

Use of the resonance shift due to the capacitance change of a resonant circuit excited by a spool.



Electrical Resistance (R) of the yarn in the embroidery pattern

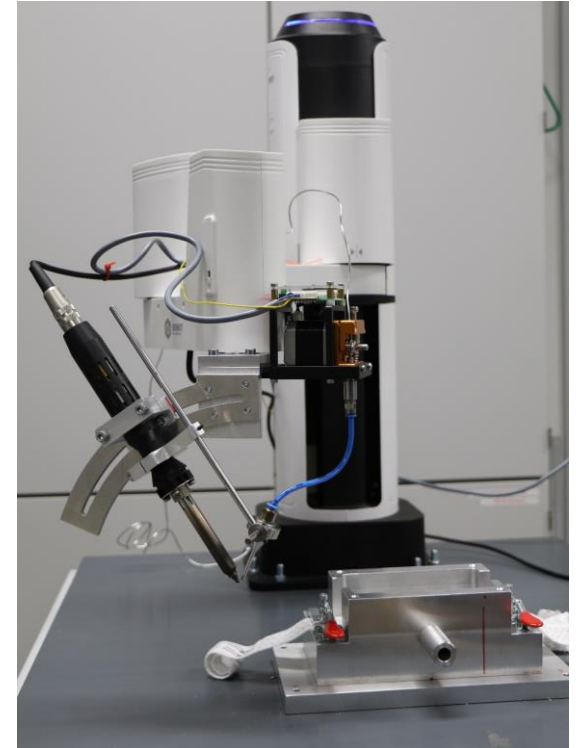


IGF project 20210 N
Forschungskuratorium
textil
Ar
Forschungsnetzwerk
Mittelstand

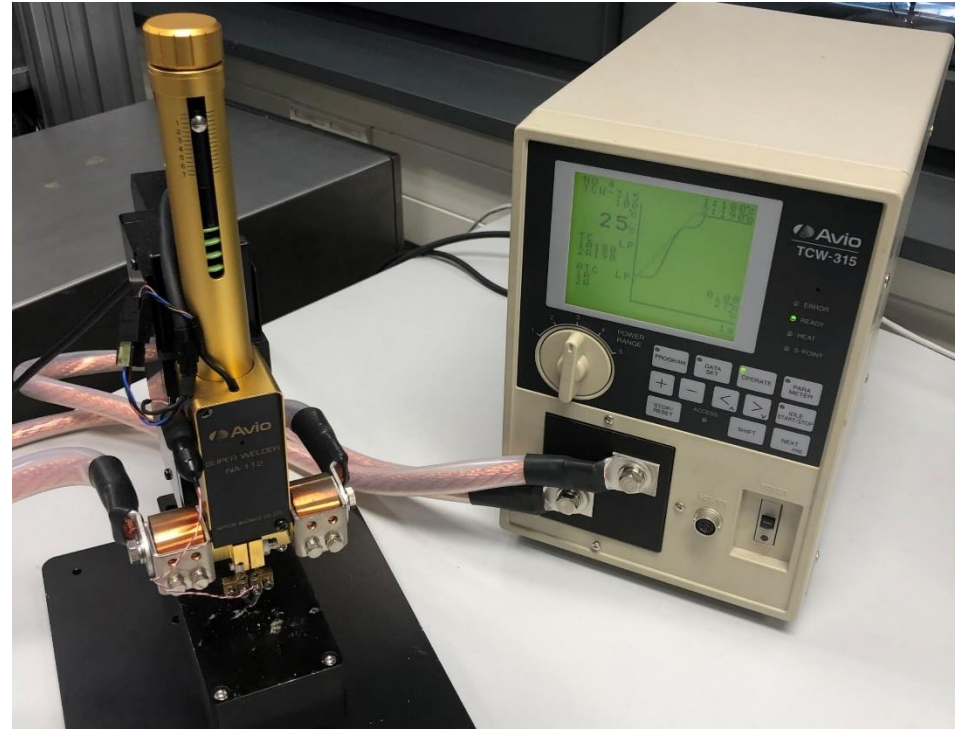
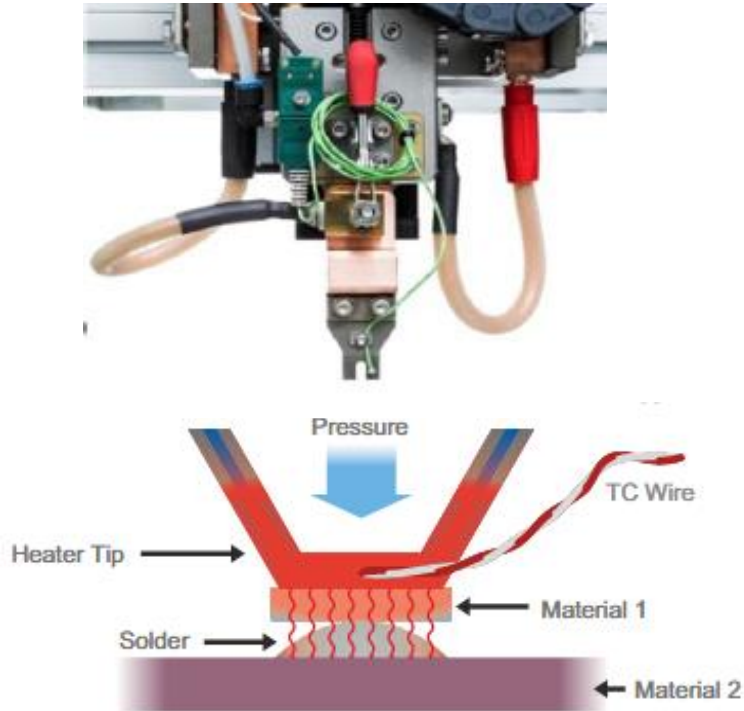
Gefördert durch:
 Bundesministerium
für Wirtschaft
und Energie
aufgrund eines Beschlusses
des Deutschen Bundestages

Contacting: laser / ultrasound soldering

- Laser: fiberlaser (1064 nm), diodenlaser (980 nm)
- Ultrasound: no flux required



Contacting: thermode soldering / bonding



Source: Nippon Avionics Co., Ltd.

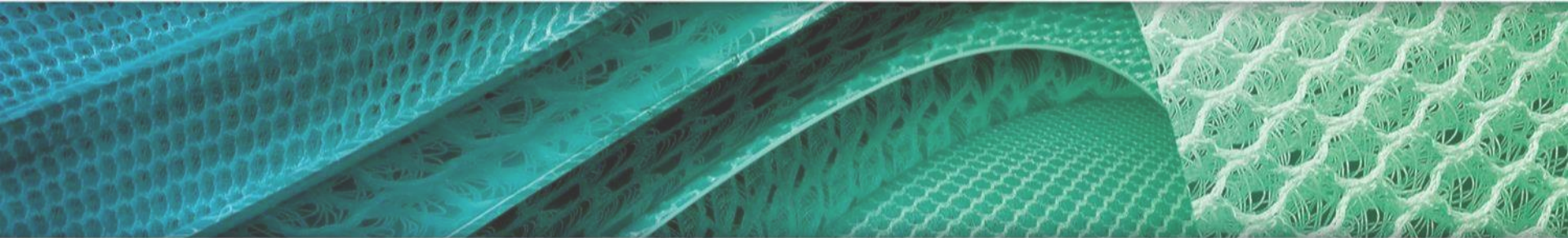
Contacting: ultrasound welding



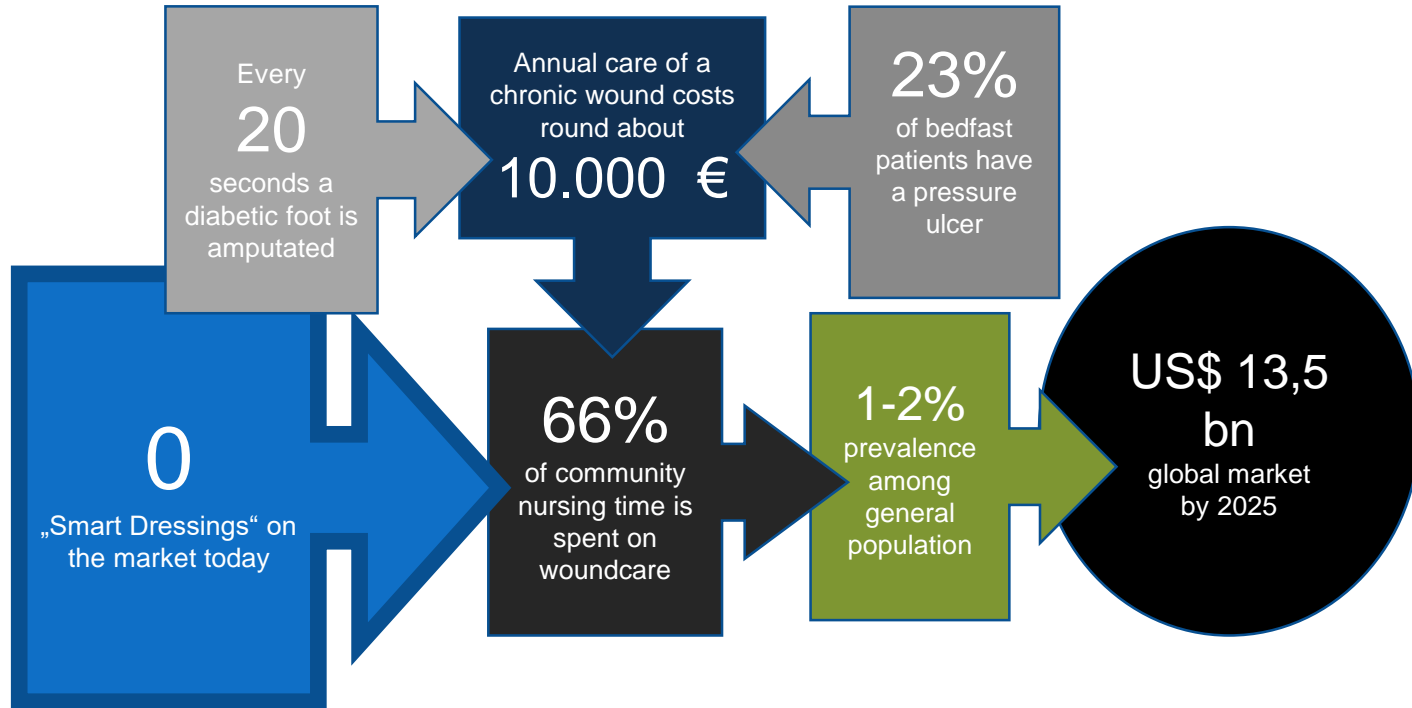
Source: TPT Wirebonder GmbH & Co. KG

Wrapped Sensor Yarns in Health Care Applications

Example: Sensory Wound Dressing for the Continuous Monitoring of Chronic Wounds

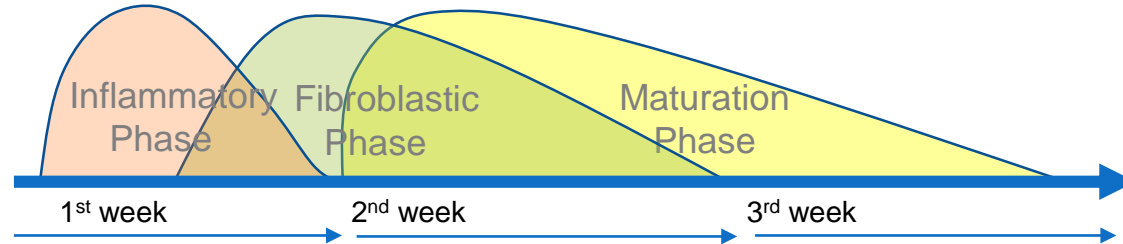


Why monitoring chronic wounds ?



Normal wound healing vs. chronic wounds

Normal Wound Healing pathways



Chronic Wounds



- A chronic wound is one that has failed to progress through the healing process in a timely manner (> 30 days)
- Chronic wounds commonly include pressure, diabetic foot and venous leg ulcers

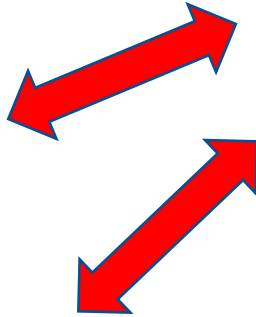


After: Conor O'Mahony; "Get smart – advances in dressing technology", Practical Patient Care magazine, November 2016

Motivation for wound monitoring

Principles of a Topical Therapy

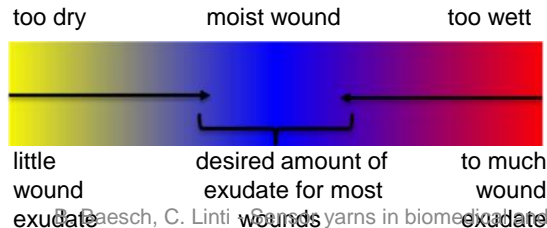
- Remove necrotic tissue and foreign particles
- Identify and eliminate infection
- Obliterate dead space
- Absorb excess exudate
- Maintain a moist wound surface
- Provide thermal insulation
- Protect the healing wound from bacterial invasion



Current Wound Monitoring Procedures

- Subjective procedure
- Manual removal and replacement of dressings every 1 – 5 days (usually every 2nd day)
- Disturbing delicate healing environment
- Patient discomfort, social impacts
- Exhausting clinical resources, consumables ...

M.O.I.S.T.

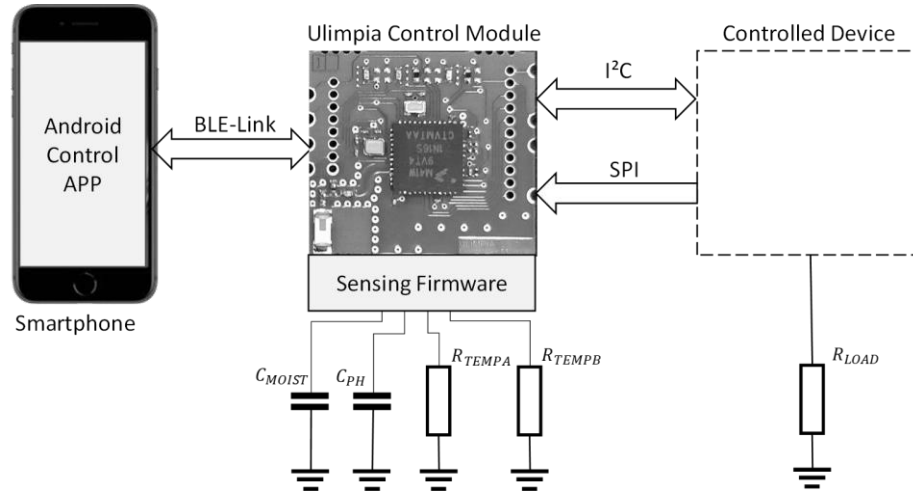


Embedded in EU Project ULIMPIA: → use of a common hardware platform



18 Partners in 6 Countries
5 Demonstrators

ulimpia-project.eu



- Ulimpia Control Module UCM controllable by mobile Android device
- Physical parameters like temperature, moisture and pH value are detected by UCM
- Data processing, storage and display on mobile Android device

Wound monitoring

Development of wound monitoring patch to...

- Sense the moisture level
 - Sense pH-level
 - Sense temperature
 - A/D Transformation
 - Wireless data transfer (BLE)
-
- continuous monitoring in a user-friendly app



DITF
DEUTSCHE INSTITUTE FÜR
TEXTIL+FASERFORSCHUNG

Fraunhofer
EMFT

KOB

GED

NXP

Principle of measurement

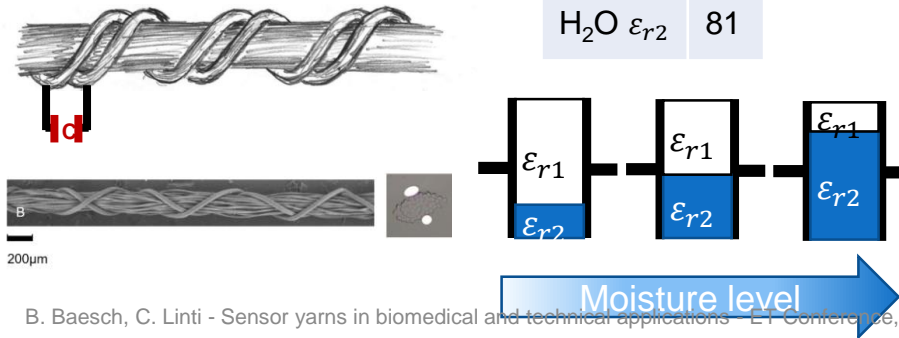
Moisture Sensor



- Fiber based sensor → yarn
- Principle of a plate capacitor
- Capacitive moisture signal → Capacitance as signal

$$C = \epsilon_0 \epsilon_r \cdot \frac{A}{d}$$

Material	ϵ_r
Air ϵ_{r1}	1
H ₂ O ϵ_{r2}	81



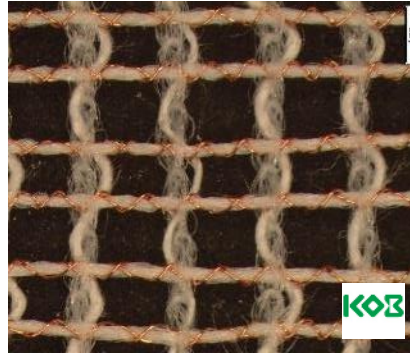
Moisture sensor

Yarn based sensor



- Sensor yarn
- Covered yarn
- Core covered with enamelled copper wire

Fabric integration



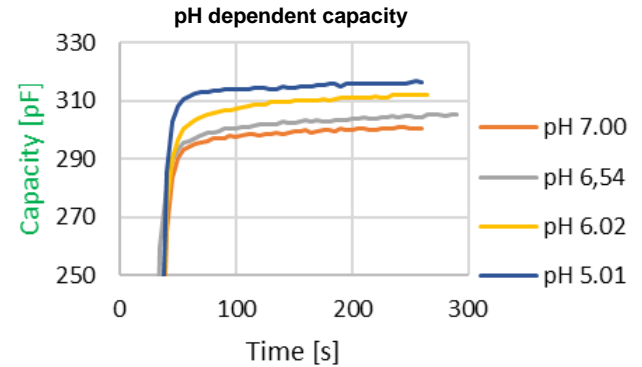
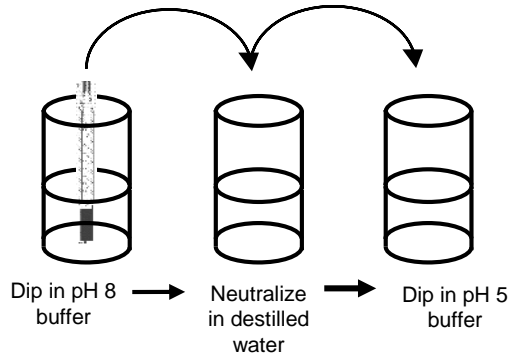
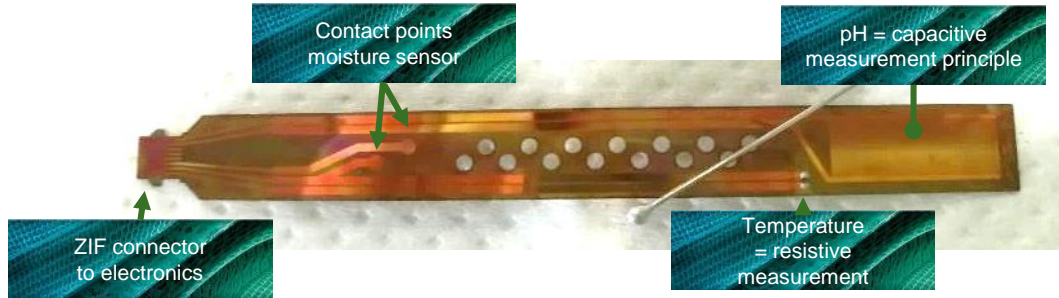
- Integration into fabric at crochet gallon machine
- Foulard treatment for activating stretch
- Conformable fabric

Foam integration



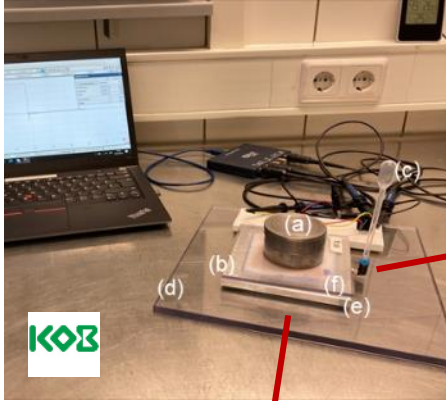
- Textile integration into absorber
- Coating with foam (PU)

pH Signal Acquisition

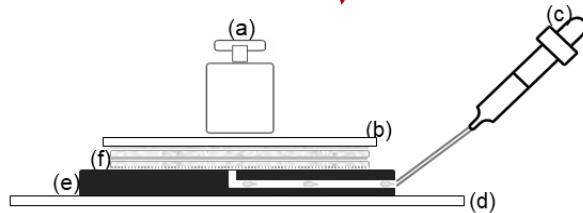


Moisture Signal Acquisition

Experimental setup for in-vitro testing



Exsudate simulating plate

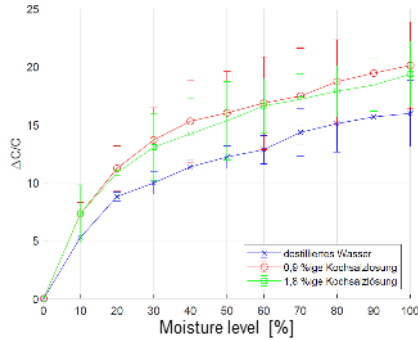


- a) Weight, simulating compression
- b) Plate for equal pressure distribution
- c) Injection for supplying test solution
- d) Spacer
- e) Exsudate simulating plate
- f) Wound patch specimen

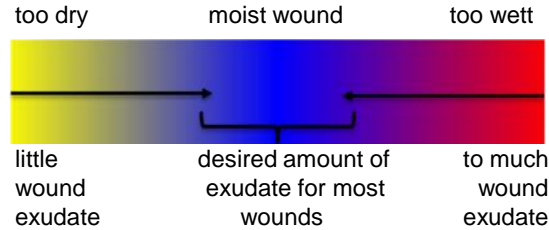


Characterization of cross influences

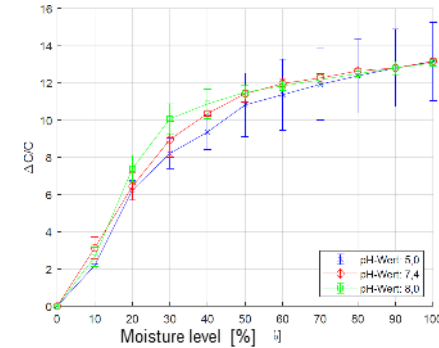
Influence by salinity



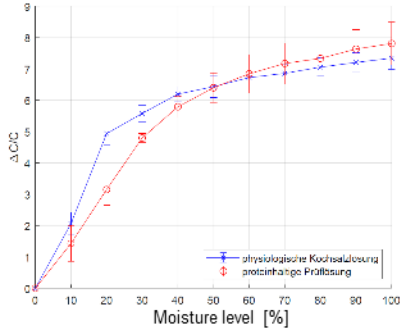
M.O.I.S.T.



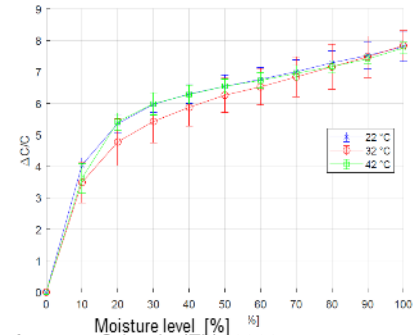
Influence by pH



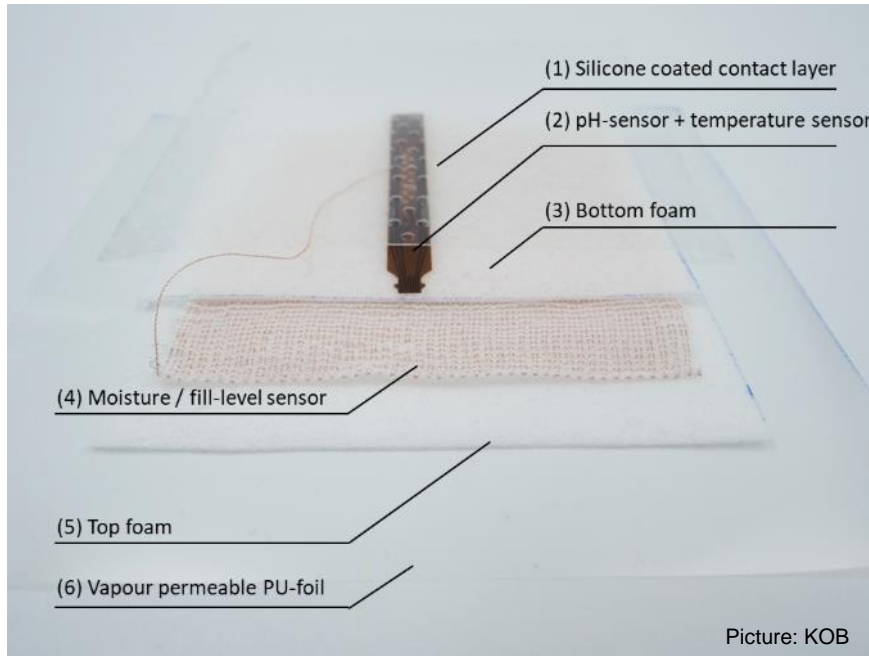
Influence by proteins



Influence by temperature



Wound Monitoring – Patch integration



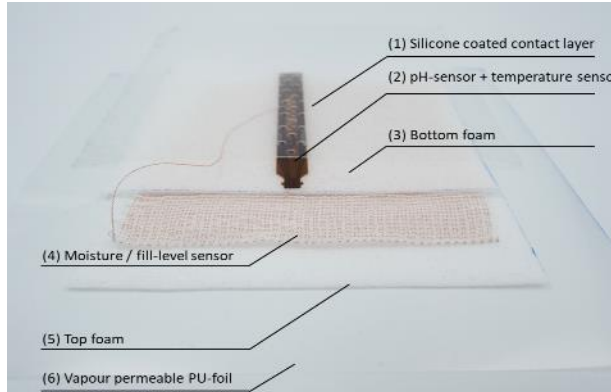
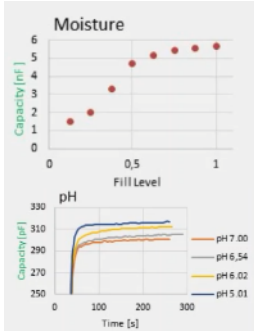
Results - Sensory Wound Dressing

for treatment of chronic wounds
 → Moist Wound Healing

Sensors for

- moisture
- pH
- Temperature

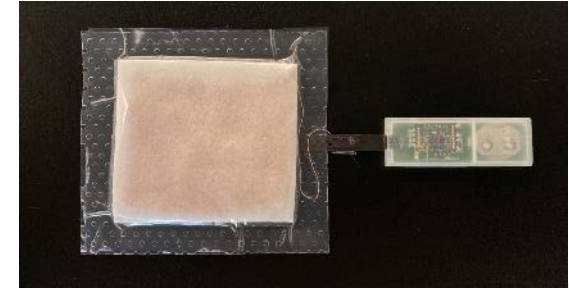
→ near to wound bed



Picture: KOB



Picture: KOB



Picture: KOB

Reduce unnecessary dressing changes!

Early detection of inflammation due to bacterial infection

→ Improvment in the healing of chronic wounds.



Conclusion

- high-level integration of minimal invasive sensors in a wound dressing
- therapeutically relevant sensitivities
- Preliminary results, not yet proven in a dynamic testing environment

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Summary

- Ordinary Yarns can be functionalized as sensors by wrapping
- This Sensor Yarns can be processed like conventional yarns
- They can be used as conductors, electrodes and sensors
- Conductive yarns can be quality controlled without contact
- All kinds of textiles can be sensorized by wrapped yarns



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