FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA

E-Textiles: Materials, Technologies and Applications

Tomáš Blecha, Daniela Moravcová, Jan Řeboun

University of West Bohemia - Faculty of Electrical Engineering
Department of Materials and Technology
E-mail: tblesi@fel.zcu.cz

KET

ket.zcu.cz

Overview

- University of West Bohemia
- E-textile introduction
- Conductive threads
- E-textile technology
- Contact and encapsulation technology
- E-textile applications
- Conclusion

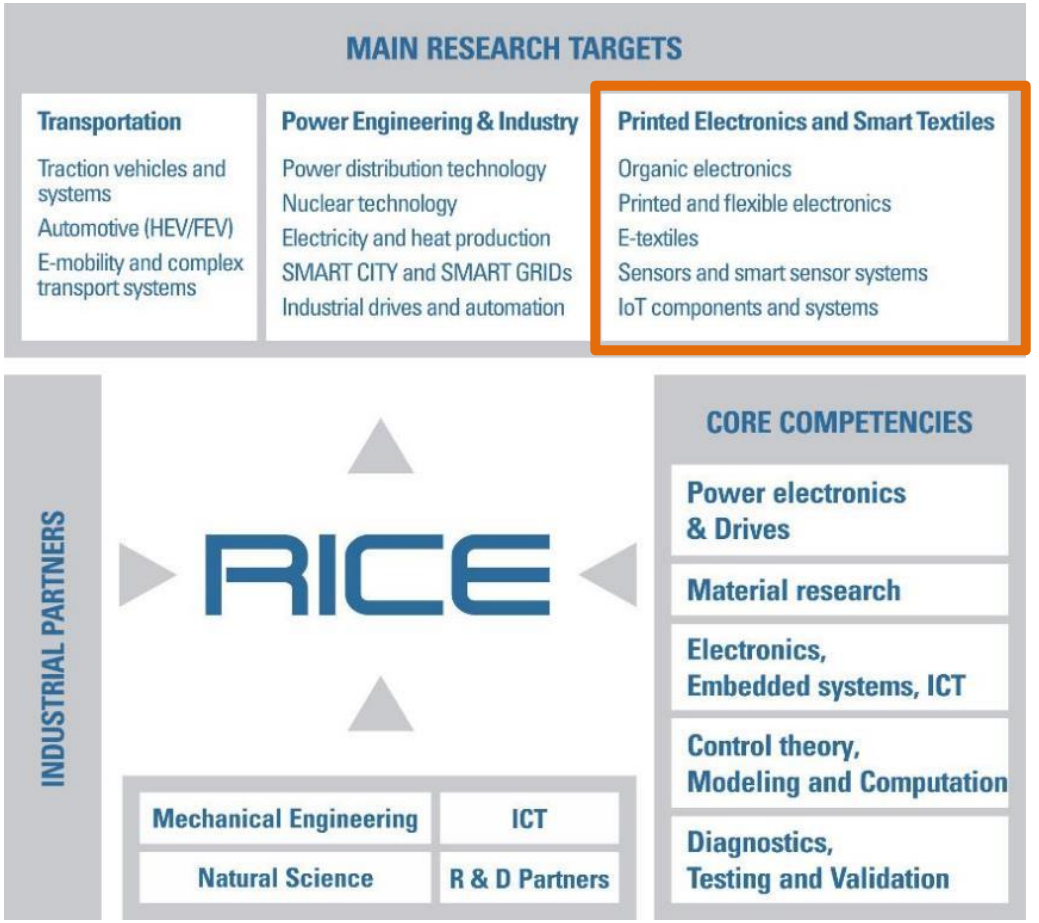
University of West Bohemia

University of West Bohemia

KET

Faculty of Electrical Engineering

- Department of Electronics and Information Technology
- Department of Power Engineering
- **Department of Materials and Technology (KET)**
- Department of Power Electronics and Machines
- Department of Electrical and Computational Engineering
- **Research and Innovation Centre for Electrical Engineering (RICE)**



E-textiles introduction

E-textiles introduction

Wearable - A fully functional, finished electronic product specifically designed be worn on the body.

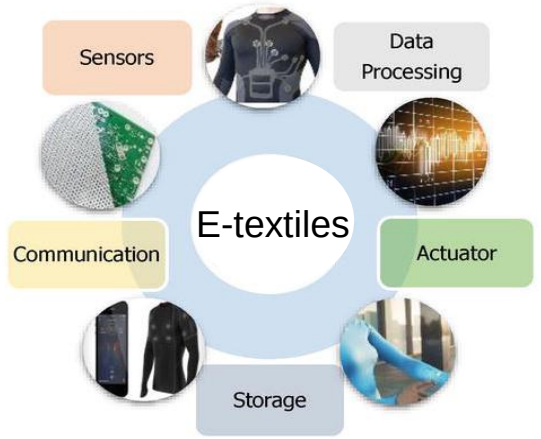
IPC

E-textile - A textile structure (fiber, yarn, fabric or finished product) permanently integrated with electrical and/or electronic functionality.

IPC

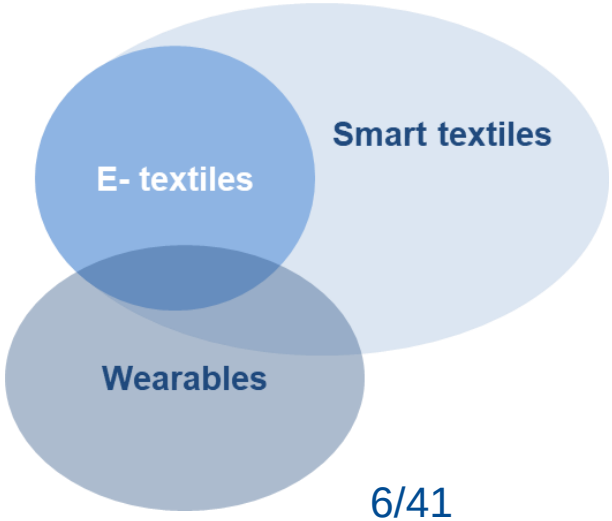
E-Textile Wearable - A textile-based end product permanently integrated with electrical and/or electronic functionality designed to be worn on the body, with or without detachable components.

IPC



Possible elements of e-textiles.

- Lack of standards slows down the smart textiles industry
- The first standards are coming
- The standards are important – they can set the **'rules of the game'** for markets that want to develop and adopt new technologies.



The relationship between wearable electronics, smart textiles and e-textiles.

E-textiles introduction

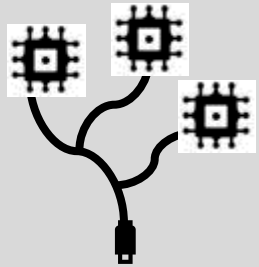
Textiles

- Soft
- Lightweight
- Breathable
- Flexible
- Shapeable in all 3 dimensions
- Convenient
- Washable
- Low thermal stress max. up to 200 °C

E-textiles

- After integrating electronics into textiles, it is necessary to preserve as many textile properties as possible.
- Therefore, it is necessary to use miniaturized electronics, new contacting, encapsulation and integration technologies.

Electronics



- Hard
- Solid
- Usually inflexible
- Dimensionally stable
- Susceptible to moisture
- Relatively higher weight
- Higher temperatures > 230 °C required for processing and conventional assembly

- Simply adapting conventional electronic technology is not sufficient

E-textiles introduction

Level of integration

High

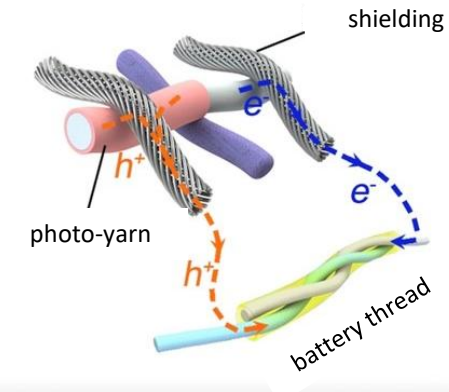
Low

4th Level of integration — **Full textile solution** - all components of the electronic equipment are made of textiles or have a textile finish,

3rd Level of integration — **Mixed solution** - an electronic device consisting of one or more components made of a textile or textile treatment and combined with permanently or non-permanently attached electronic components, e.g. a smart firefighting suit..

2nd Level of integration — **Permanent integration .** The electronic device is attached to the textile in such a way that it cannot be removed without destroying the product, e.g. sewn, welded, glued, etc. to the textile.

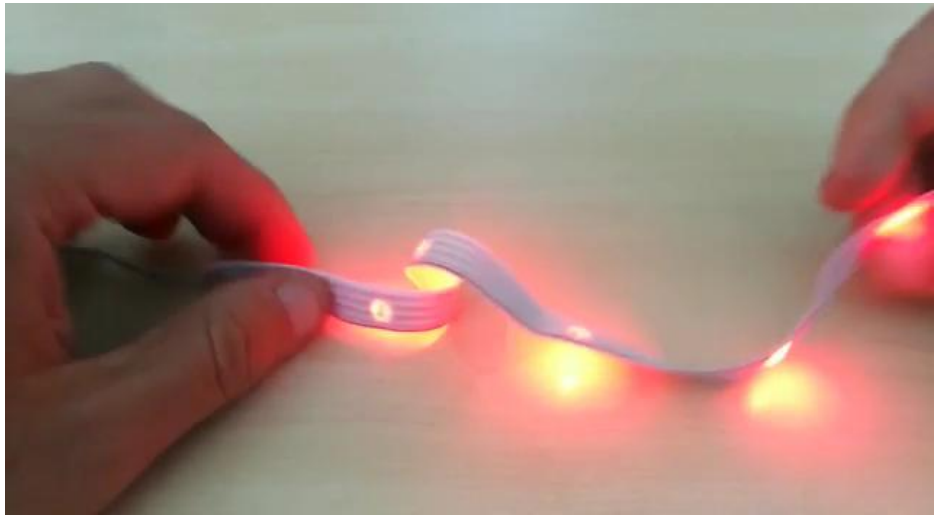
1st Level of integration — **Removable solution** - The electronic device is integrated into the fabric in such a way that it is removable (e.g. via pocket, Velcro, button, etc.) without destroying the product, e.g. during washing,



E-textiles introduction

E-textiles (garments) shall meet the following requirements

- User comfort and convenience
- Light weight and not bulky electronics and sensors
- High washing resistance
- High mechanical durability
- Breathability
- Comply with norms and standards
- Protective clothing: withstand harsh environment



Challenges for e-textiles

- Flexible batteries and energy harvesting systems (e.g. photovoltaics, piezoelectric systems, etc.) suffer from low levels of generated.
- Most of the industrial electronics manufacturing technologies (soldering, surface mount, vacuum technologies, etc.) are not compatible with textile manufacturing. It is necessary to come up with new technologies ➡ the aim of our research.
- A number of textile products suffer from a lack of resistance to washing ➡ the aim of our research.

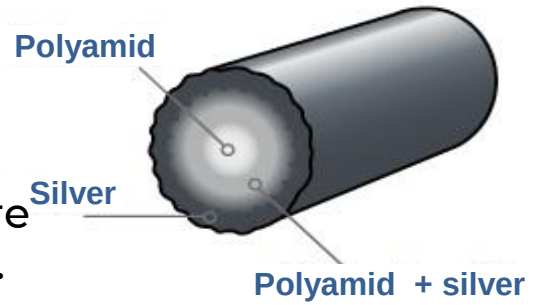
Conductive threads

Conductive threads

- E-Textiles are based on the electrically conductive fibers and yarns that can be used in combination with textile techniques such as sewing, weaving and knitting.
- Most conductive yarns (theads) are produced by the industry for anti-static, EMF shielding and for textiles with antibacterial effects for yarns containing silver.
- Conductive yarns can be used to:
  a) Interconnection
  b) Heating
  c) Sensor
  d) Textile electrodes (textrodes)
  e) Antennas
  f) Electrostatic shielding
  g) Antistatic application

Metallized synthetic fibres

- Coated synthetic fibres (polyamide and polyester).
- Resistant to stress and bending, but not very resistant to wash cycles (endurance of about 30 cycles).
- Relatively low-temperature resistance (tend to shrink).
- Textile electroplating is the technology of applying metals.
- Easy to contact.
- The linear resistances of the yarns are relatively high 100 Ω/m to 1000 Ω/m.

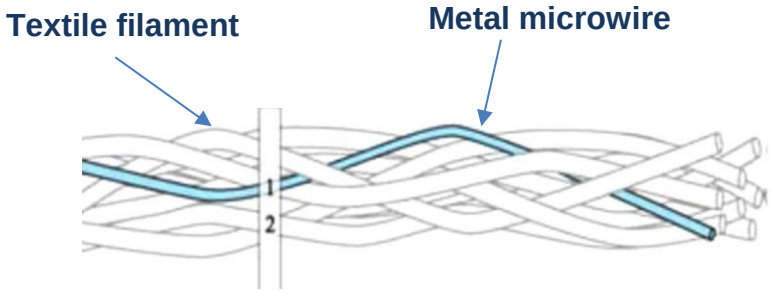


Conductive threads

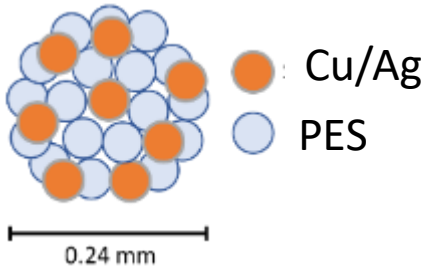
Hybrid conductive threads

Different types of hybrid yarns sold by Co. VUB under the CleverTex brand.

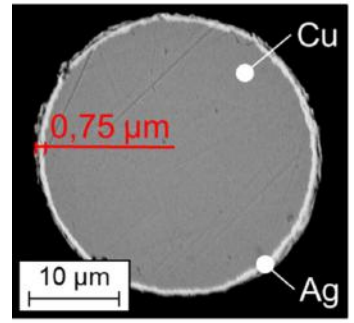
- Threads twisted (plied) from textile filament fibers and metallic microwires with a diameter of 30 µm – 40 µm.
- Synthetic filament fibers are most often PESh mutifilament fibers (14.5 µm), but can also be PA or flame retardant meta-aramide or elastic fibers, etc.
- Metallic microwires (silver plated copper, brass, bronze, constantan, stainless steel, etc. with a diameter of 30 µm - 40 µm).
- The mechanical strength and fineness of threads are ensured by their textile part
- **Difficult to manufacture:** conductive fibers are taken as impurities in conventional textiles (machine stops), suffer from machine grommets, wire looping, etc.

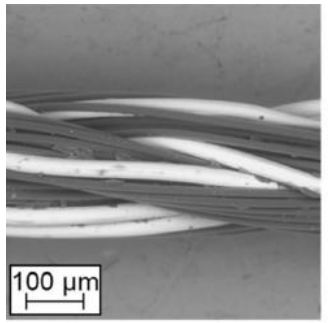


Hybrid sewing thread made of 1) metallic micro wires and 2) filament textile fibers.



Example of hybrid thread containing Ag plated Cu microwires

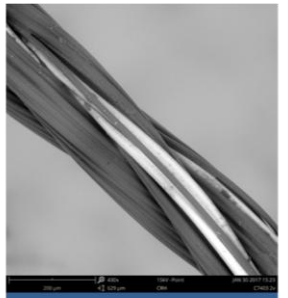




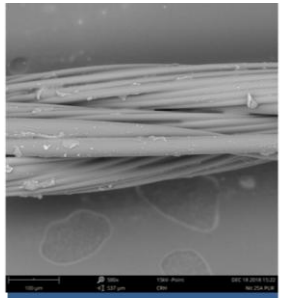
Conductive threads

Hybrid conductive threads

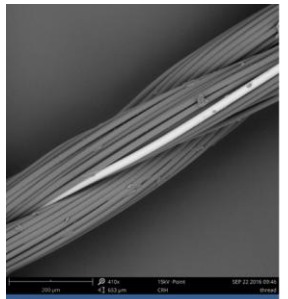
- Advantages
  - Almost the same mechanical properties as textile threads (can be used for sewing, weaving and knitting), fully compatible with all standard textile processes.
  - Can be soldered, crimped, can be produced in an insulated design.
  - High resistance to mechanical load and washing (> 100 washing cycles for knitted e-textiles).
  - Health and safety according to REACH Regulation 1907/2006/EC.
  - Low linear el. resistance down to 0.6 Ω/m.
- Disadvantages
  - Not conductive around their entire circumference like metallized threads ➡ sometimes more complicated contacting, better for threads with more wires.
- Applications: conductive interconnections, heating structures, flexible printed circuit boards of textile electrodes, textile sensors.



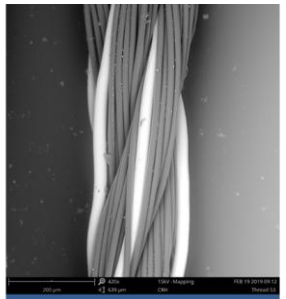
25A
4x Cu/Ag microwire
Conductive thread



25A PUR
4x Cu/Ag PUR insulated microwire
Conductive thread



7A
1x stainless steel microwire
Temperature sensor thread



53A
4x brass microwire
Conductive thread

E-textile technology

Conductive flat fabrics

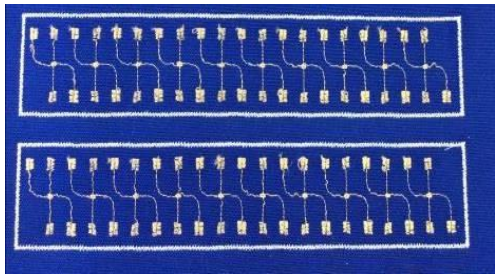
- Flat fabrics are fabrics whose 2 dimensions are proportional and whose thickness with respect to the other 2 dimensions is negligible.
- The flat fabrics can be divided into:
  - Woven
  - Non-woven
  - Knitted

Flat e-textiles can be prepared:

- By embroidery with conductive threads
- Fix wires on conductive yarns with needle and thread (TFP -Tailored Fiber Placement technology)
- Weaving conductive threads into woven fabrics
- Knitting conductive threads into knitted fabrics
- Printing of conductive pastes and inks
- Electroplating of nonwovens

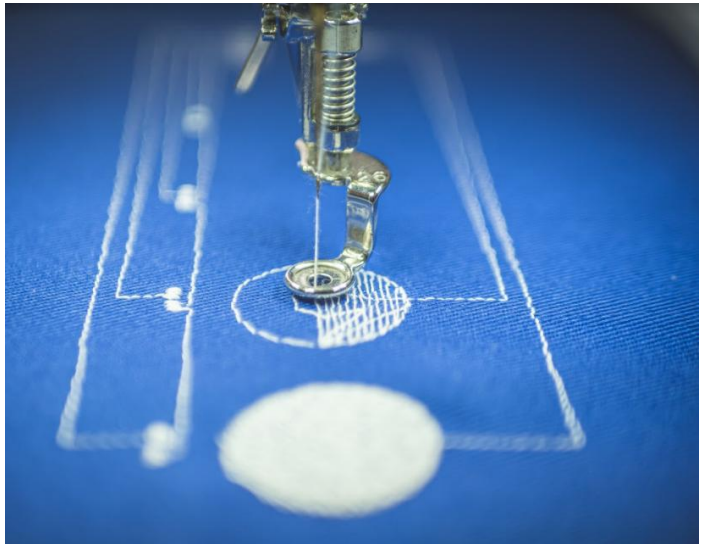







Embroidery technology

- Embroidery is a traditional technique of textile decoration.
- Big difference between decorative embroidery and functional embroidery (sometimes also called technical E-broidery = electronic embroidery).
- If the thread breaks in decorative embroidery, the machine goes back a few cm and continues sewing x functional embroidery loses function (breaks the circuit).



Advantages

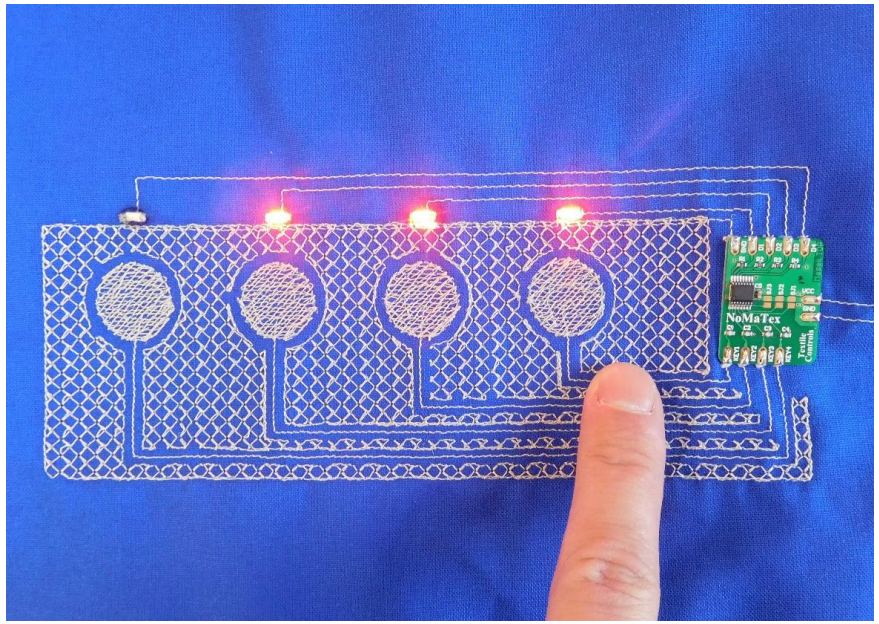
- Any two-dimensional conductive pattern can be quickly created.
- Easy customisation, quick machine reconfiguration (digital embroidery).
- Multiple threads can be used at the same time for one embroidery.
- It is possible to stitch over each other (e.g. to form non-conductive insulating bridges).

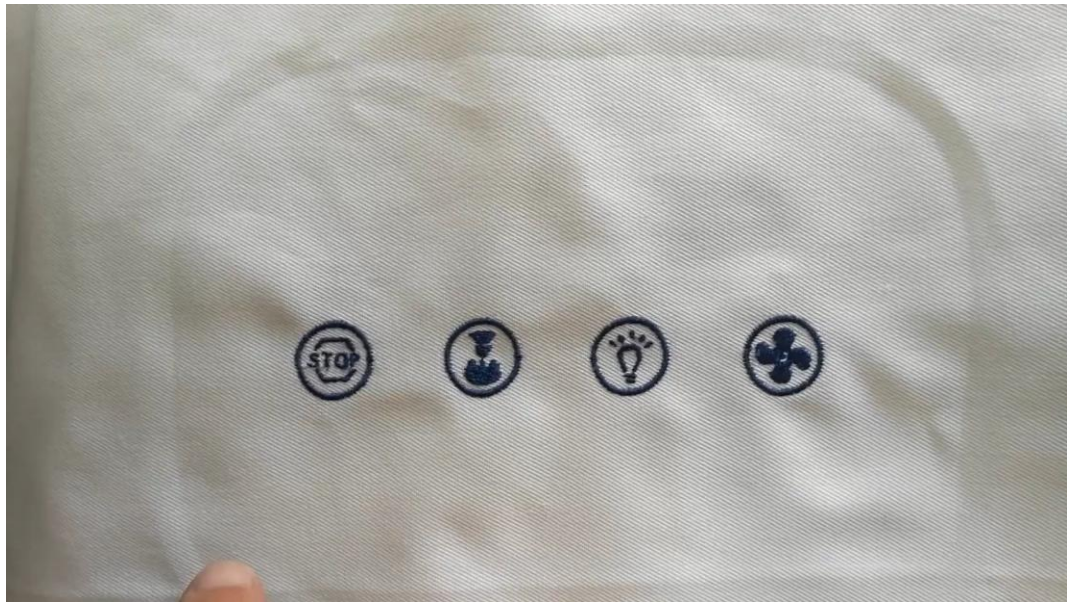
Disadvantages

- Of all the production methods, embroidery is the most stressful for the conductive threads (high friction forces in the eye of the sewing needle, high tensile forces of the hook, large thread bends during sewing).
- The embroidery is less abrasion resistant and has less resistance to washing.

Embroidery technology

Examples of realizations from our university

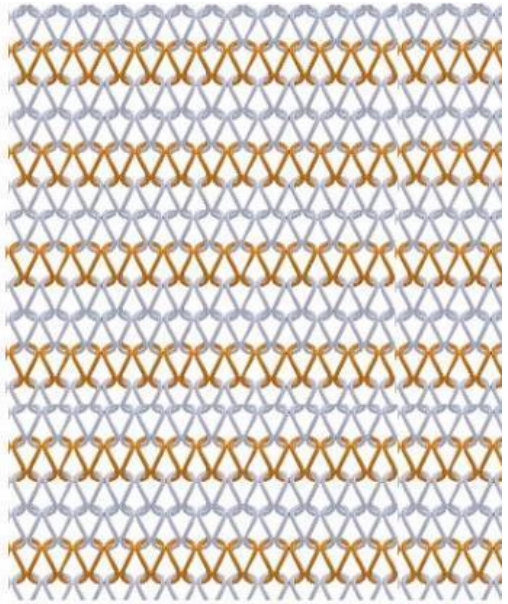


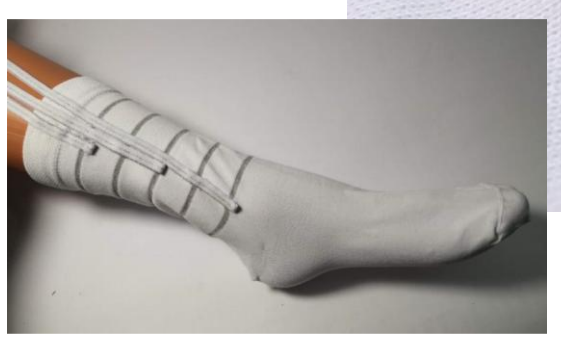


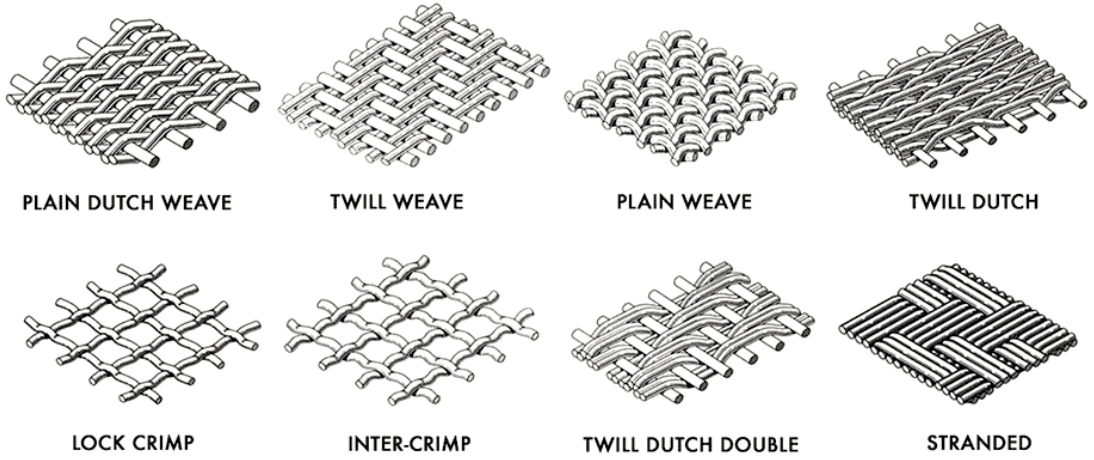
Capacitive buttons with feedback LEDs.

Knitting and weaving technology

- Knitting / weaving machines
- Conductive thread braided / arrested in the fabric
- Limited pattern shape – fixed geometry
- Flexibility, breathability

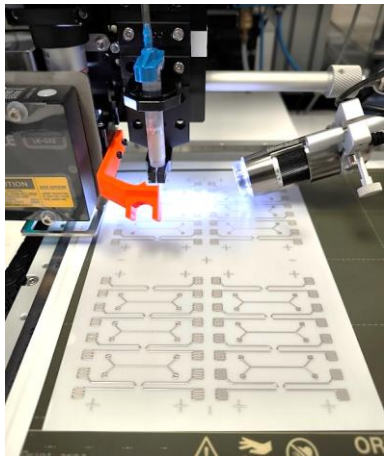


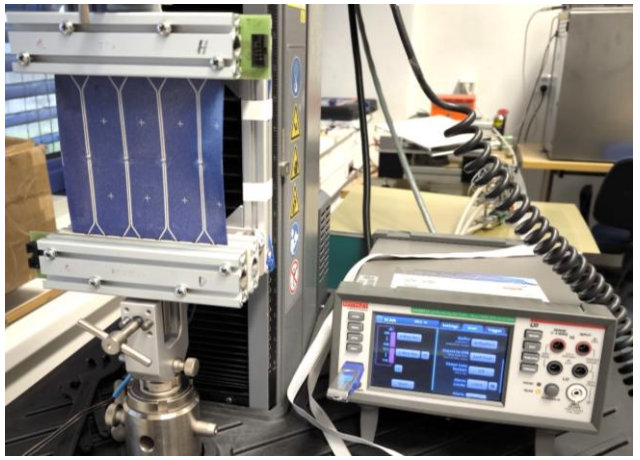


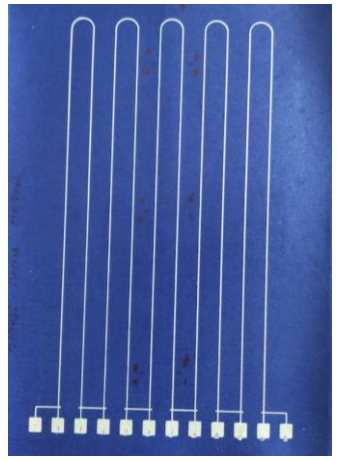


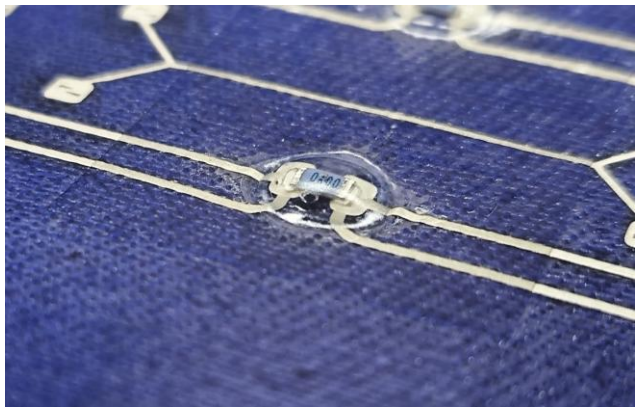
Printing and lamination technology

- Conductive ink printing on TPU (screen printing, direct-write
- SMD component assembly and encapsulation
- TPU (system on foil) lamination on textile
- Unlimited pattern shape – variable
- Fine line capability
- Flexibility, freedom in fabric selection
- Limited breathability - perforation or selective lamination of TPU





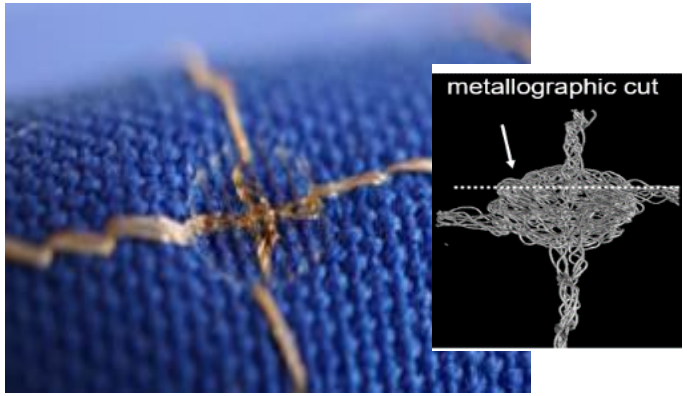




Contact and encapsulation technology

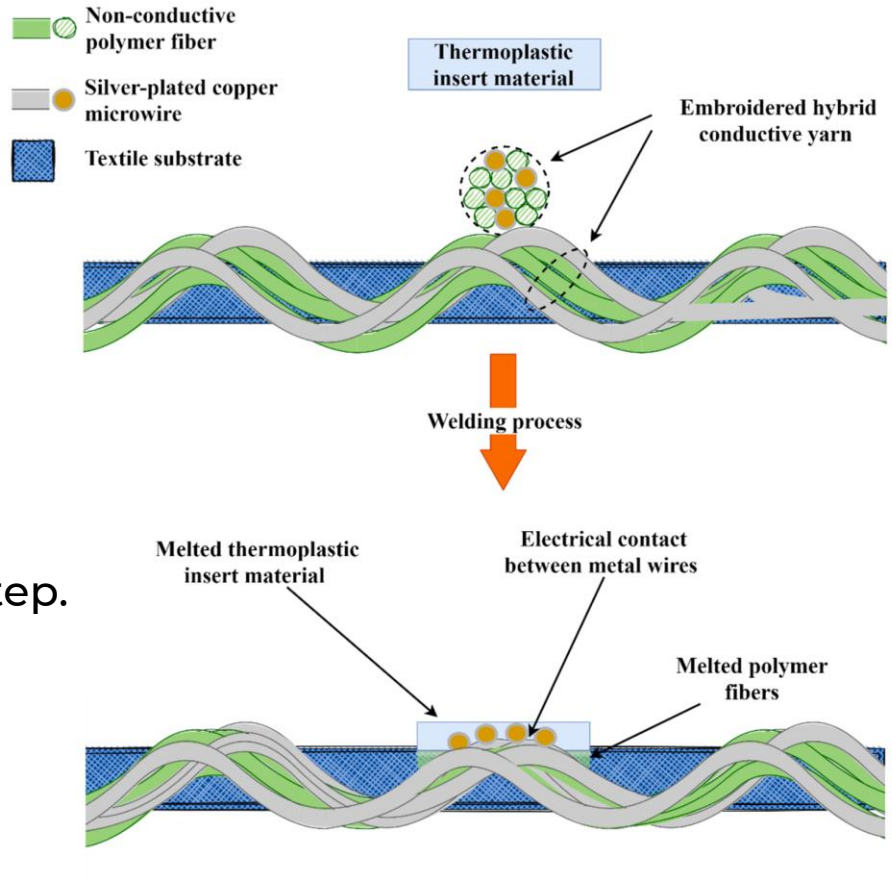
Thermoplastic ultrasonic welding

- **Necessary for e-textiles:** high quality, inexpensive, stable, reliable and durable electrical contact.
- **Goal:** To develop an alternative technology to soldering, crimping and bonding for interconnection of conductive threads.
- Compatible with textile production processes.
- El. resistance of the US welded joints ranged up to 20 mΩ.
- Reliable, efficient and scalable contacting technology is essential tc increase the productivity and reliability of e-textile products.
- **Advantage:** el. contact creation and encapsulation in one process step.



US welded joint of conductive threads

US welding machine

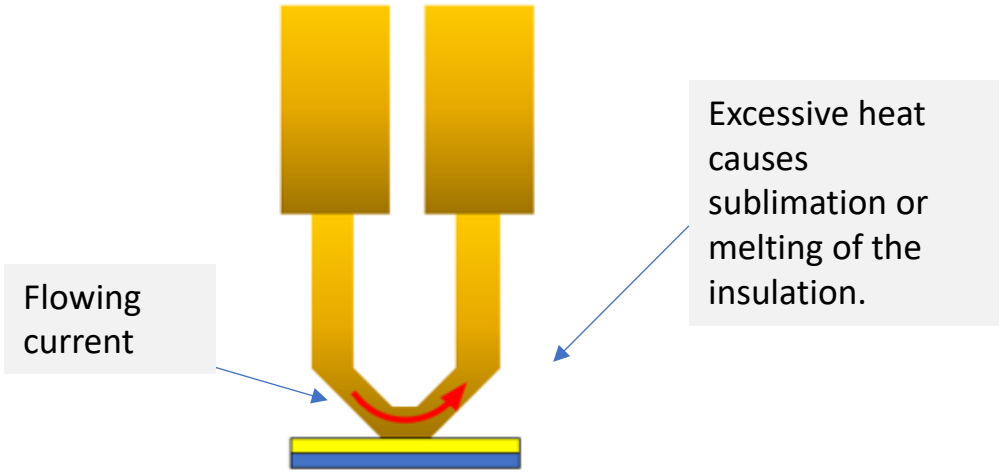


DILS, CH. KALAŠ, D. ŘEBOUN, J. SUCHÝ, S. SOUKUP, R. MORAVCOVÁ, D. KRSHIWOBLOZKI, M. SCHNEIDER-RAMELOW, M. Interconnecting embroidered hybrid conductive yarns by ultrasonic plastic welding for e-textiles. TEXTILE RESEARCH JOURNAL, 2022, ISSN: 0040-5175

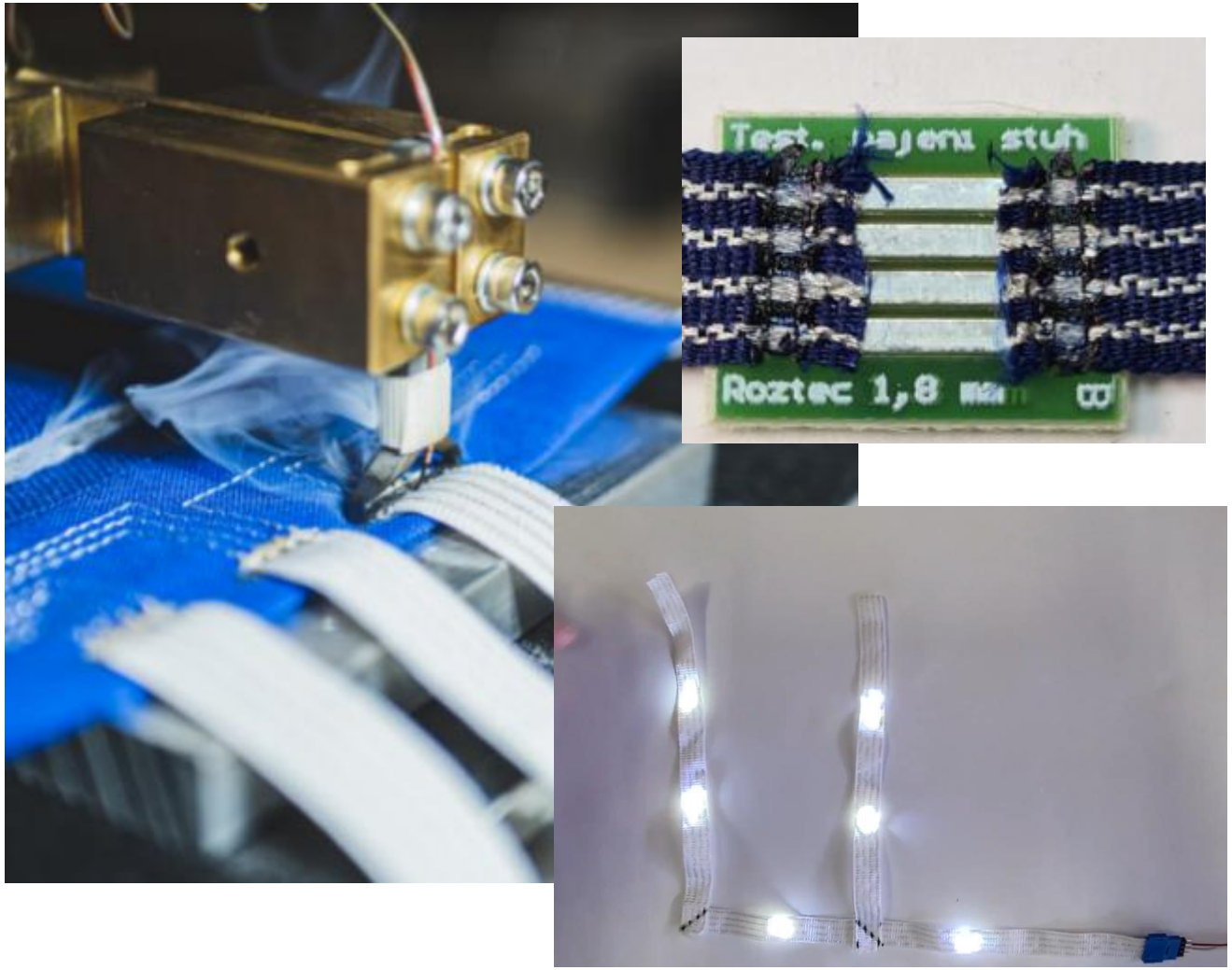
Hotbar resistance welding

Welding electrode

Welded materials



Hotbar electrodes

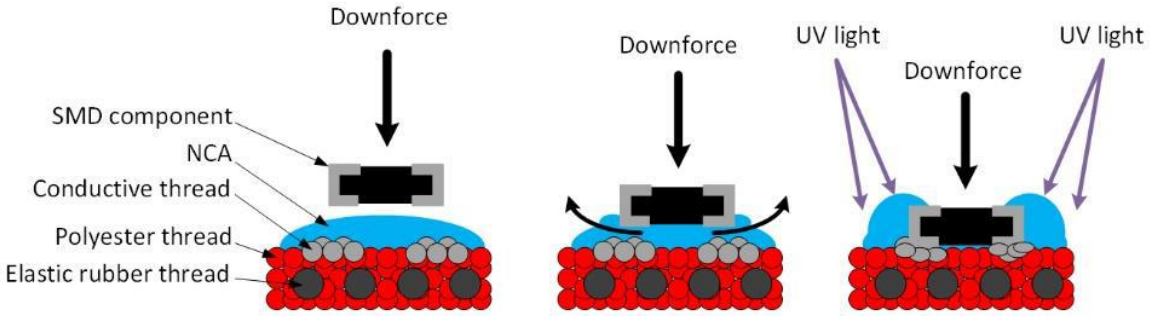


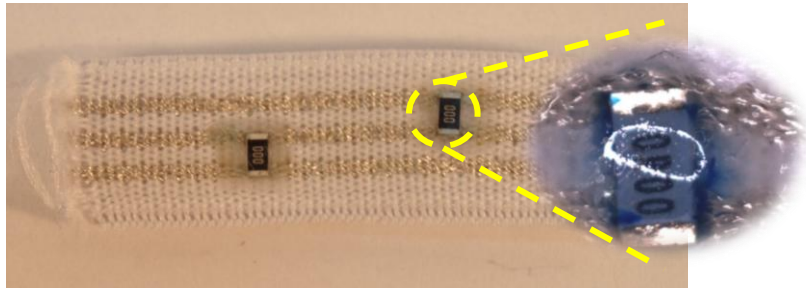
- Insulated microwires (even by thermosetting insulation) can be welded.
- A metallurgical joint can be formed.

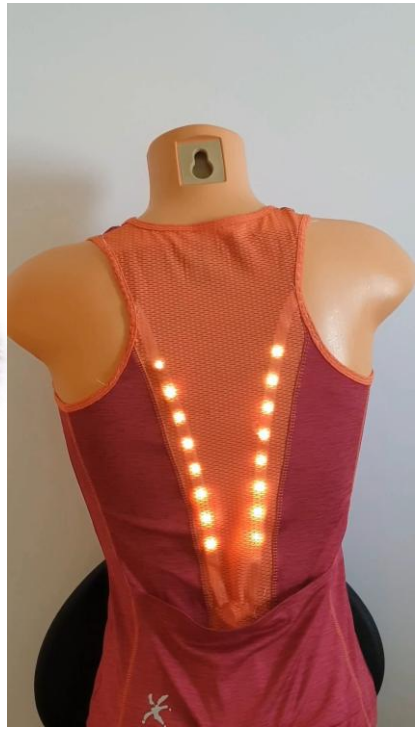
Direct integration of electrical elements on textile

Non-conductive UV curable polymers

- Contacting SMD electronic components directly on textile substrates.
- Advantages of non-conductive UV curable polymers for e-textiles:
  - Almost no heat stress on the substrate and components
  - Curing of the joint in a matter in seconds
  - Properties of the connection better or comparable to the connections made with conductive adhesives
  - Contacting also creates protection of the component from the external environment (encapsulation)
  - Available UV curable adhesives on the market
  - Easy implementation of the technology in industrial production.





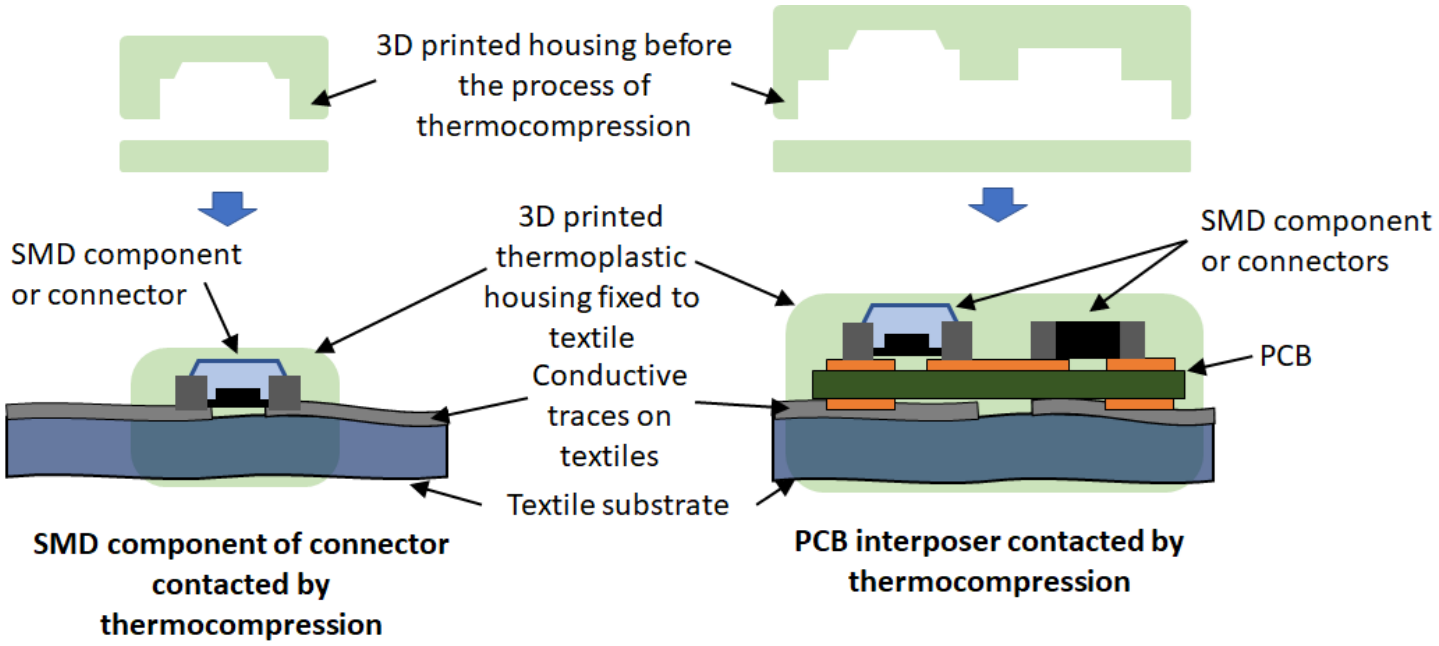


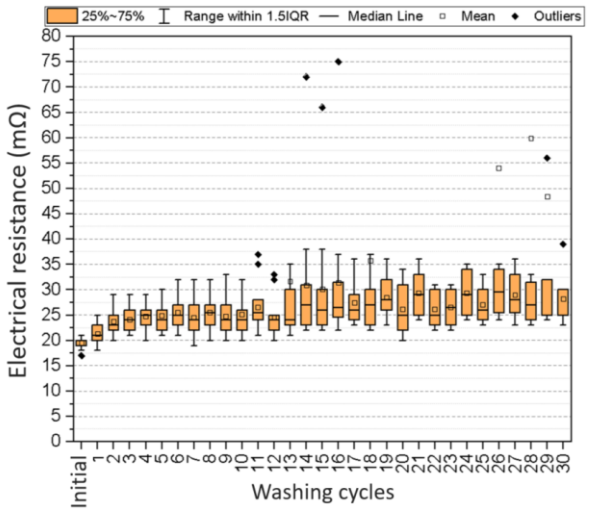
Direct integration of electrical elements on textile

Thermo-compression contacting and encapsulting technology with 3D printed thermoplastic enclosers

- Electrical contact realization and encapsulation in one production step
- Low-resistance electrical contacts and fluid-resistance encapsulation

3D printing of a housing with a cavity for a component/ PCB → Placing the housing with the component on a textile substrate → Thermocompression - lamination under elevated temperature and pressure





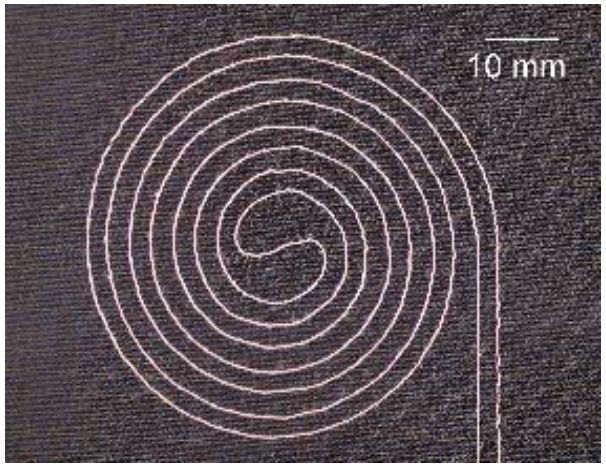
Washing test of a sample with a conductive filament with Cu filler.

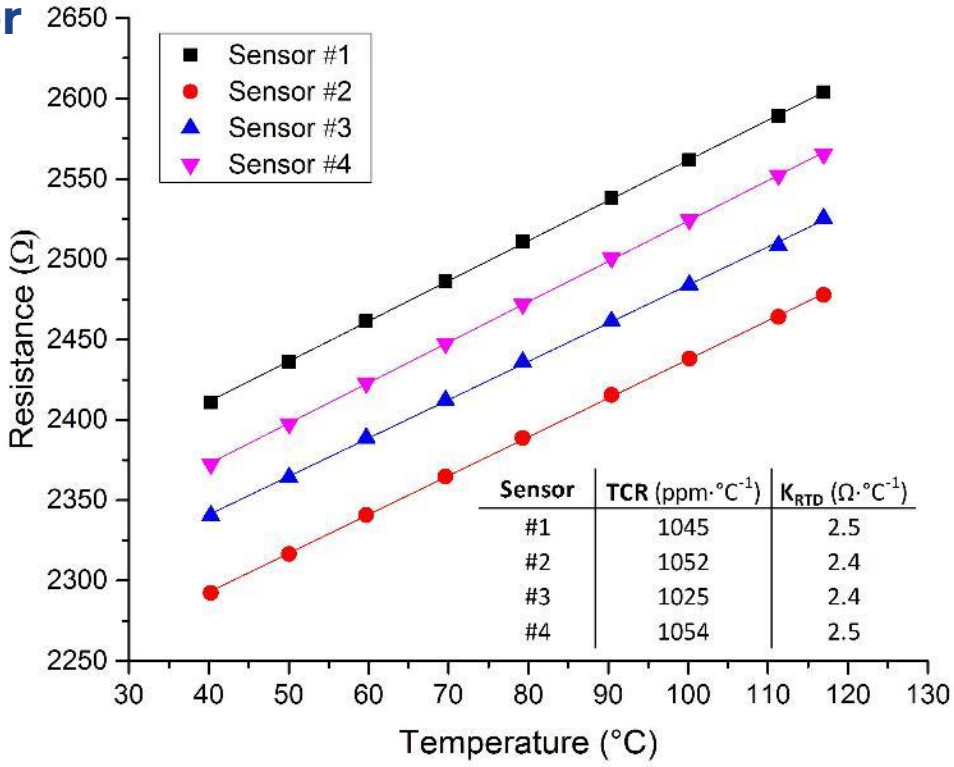
E-textile applications

Textile temperature sensor

Embroidered RTD (resistive temperature device) thermometer

- Allowing temperature measurements from a large area.
- Based on a chrome-nickel steel microwire
- Fast response to sudden temperature changes
- Resistance to more than 30 wash cycles
- Easy integration into textiles





Sensor	TCR (ppm·°C^{-1})	K_{RTD} (Ω·°C^{-1})
#1	1045	2.5
#2	1052	2.4
#3	1025	2.4
#4	1054	2.5

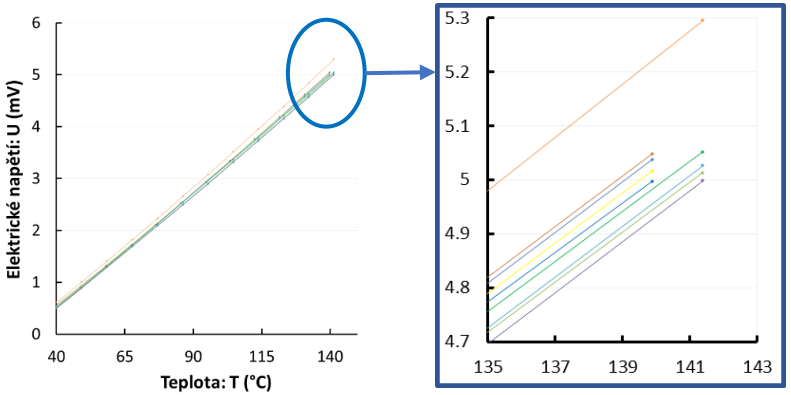
Example of calibration curves for embroidered thermometers

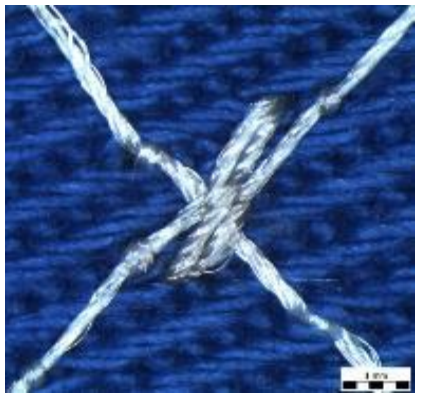
R. Polanský, et al., A novel large-area embroidered temperature sensor based on an innovative hybrid resistive thread, In Sensors and Actuators A: Physical, Volume 265, 2017, Pages 111-119, ISSN 0924-4247.

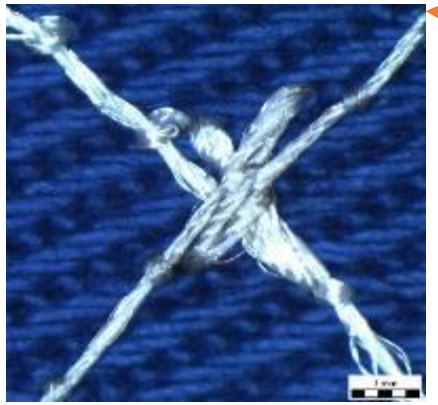
Textile temperature sensor

Embroidered thermocouple

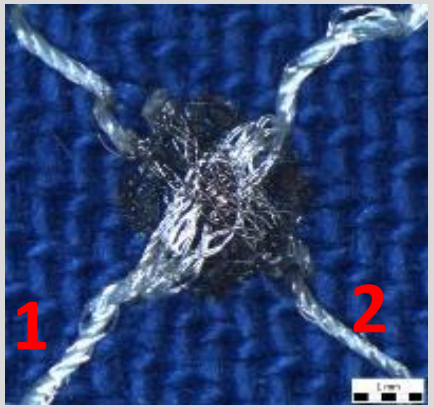
- Embroidered textile thermocouple T-type with SC of 44,1 µV · K-1 to 44,5 µV · K^{-1}
- Hybrid conductive threads with:
  - 4x Cu/Ag microwires (Ø 30 µm).
  - 4x micro wires made of constantan (Ø 27 µm).
- Thermocouple contact (thermocompression contacting and ultrasonic welding).





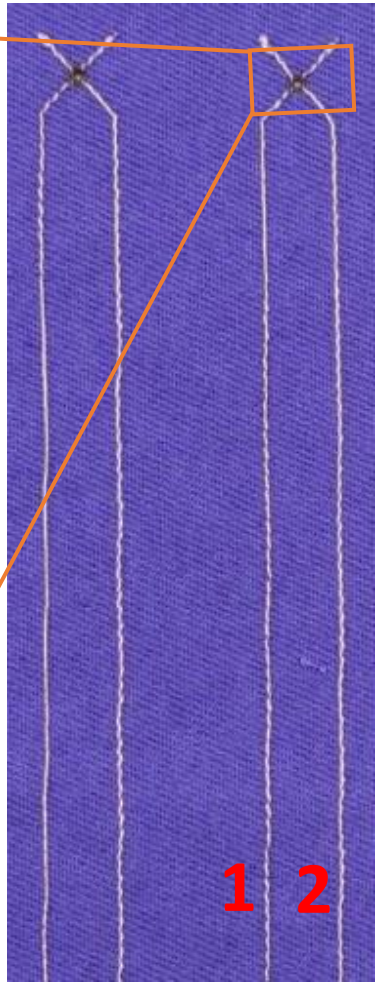


Embroidered thermocouple crossing before welding



Thermal compression welding

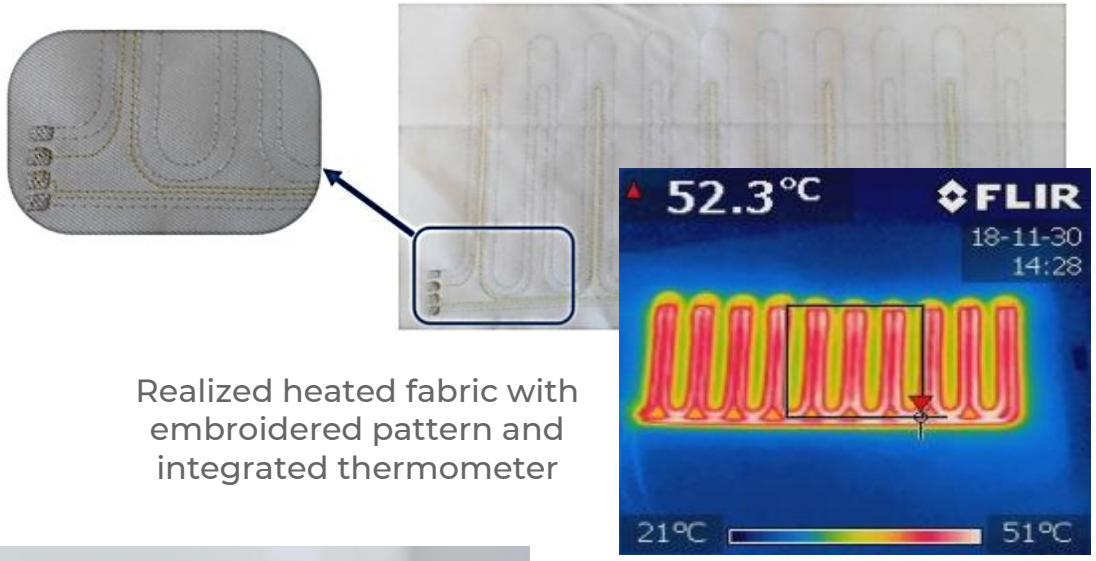
Ultrasonic welding



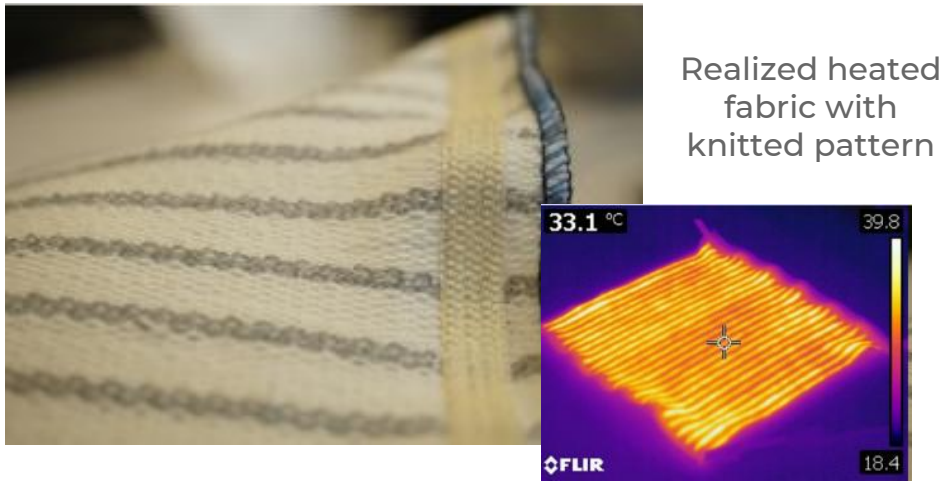
Embroidered thermocouples

Heating elements

- Heating in different zones.
- Large-area knitted / embroidered heated textiles with uniform temperature distribution.
- Seamless integration of heating threads into knitted structure – heated bed sheet.
- Heating power up to 80 W.
- High mechanical resistance, resistance to maintenance stress (washing/drying process).
- Possible integration of temperature sensor for feedback control of heating elements.



Realized heated fabric with embroidered pattern and integrated thermometer

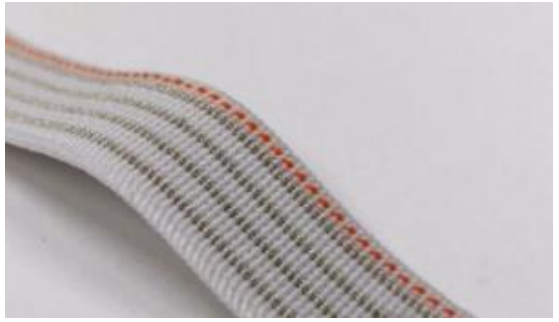


Realized heated fabric with knitted pattern

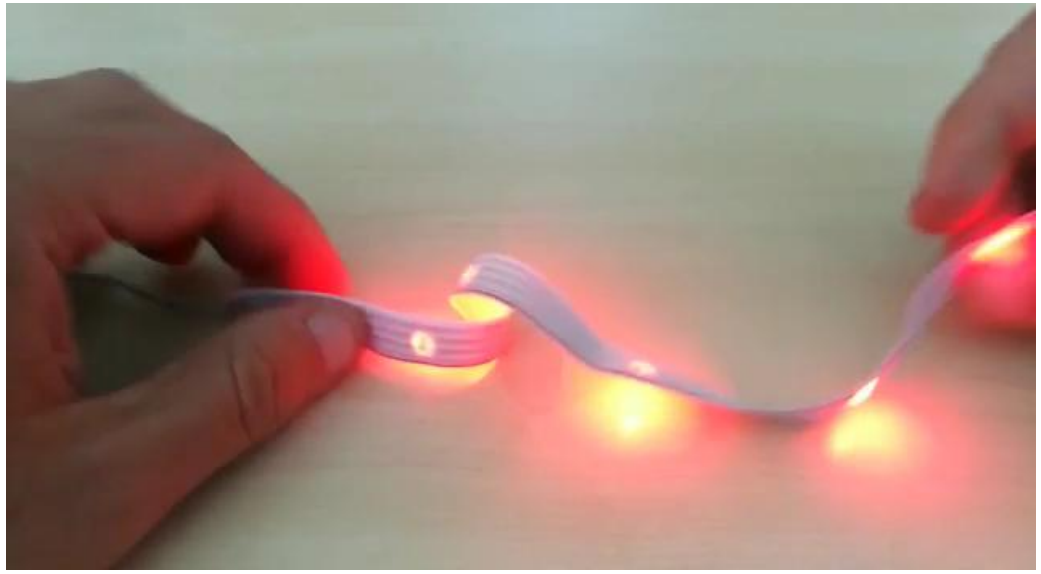
Heated bed sheet

Stretchable conductive ribbon

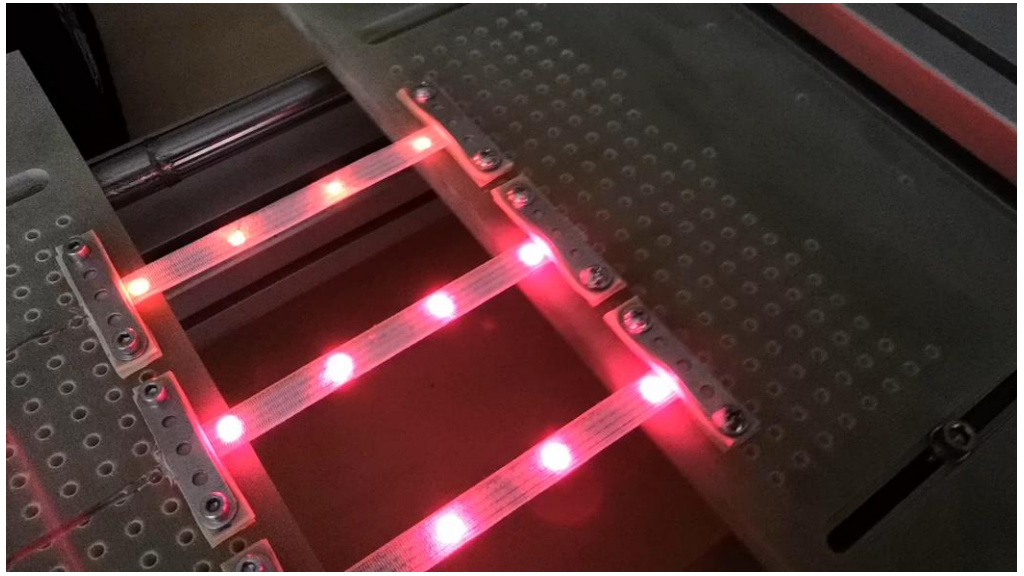
- **Stretchable up to 70 % without resistance change**.
- Withstand >25 000 cycles @ 30% stretching, >9 000 cycles @ 70% stretching.
- Maintenance resistance > 90 washing cycles @ 400 rpm, 40 °C.
- Abrasion resistance > 20 000 revolutions (ISO 12947-2).
- Possibility of direct integration of SMD components or interposers.



Four-conductor flexible ribbon



Flexible conductive ribbons with fitted LEDs

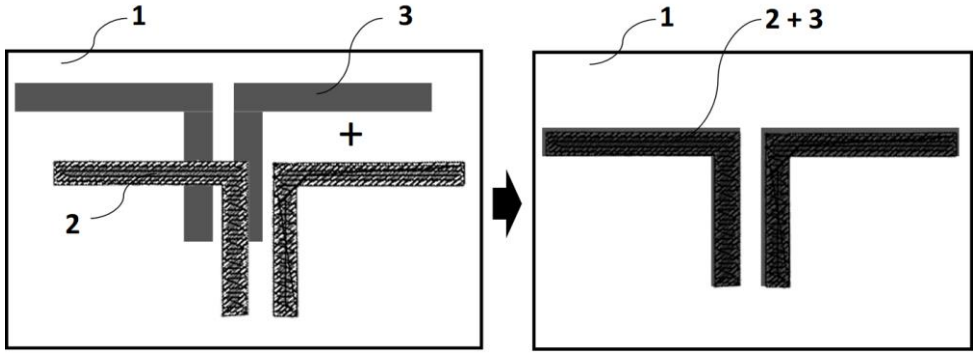


Cyclic stretch tests (after 4500 cycles)

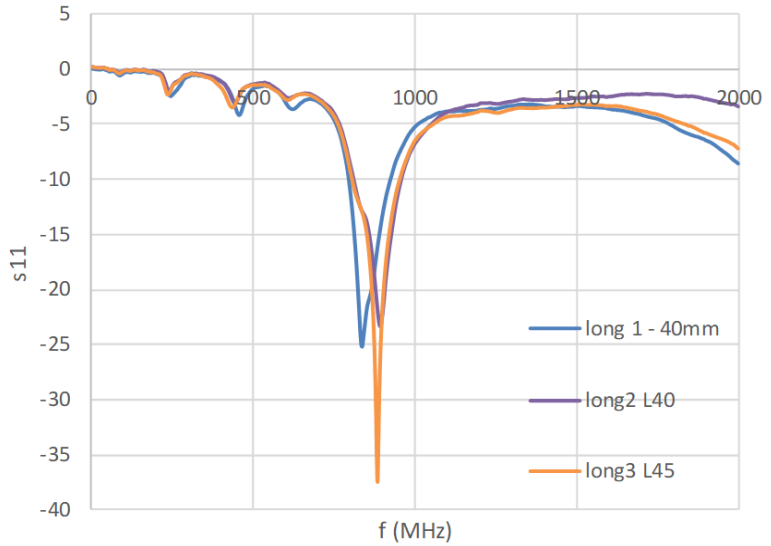
*Patent **CZ 308614 B6**, „Conductive elastic woven fabric, in particular conductive elastic woven ribbon “, 2021.*

Textile antennas

- Textile based dipole and bowtie antennas for the frequency band of 868 MHz.
- **Hybrid construction** (printing and embroidering) - better mechanical resistance.
- **Benefits:** flexibility, breathability, wear comfort, stable electrical parameters during maintenances.



Antennas layout



The dependence of the S11 parameter (reflection coefficient or return loss) on frequency

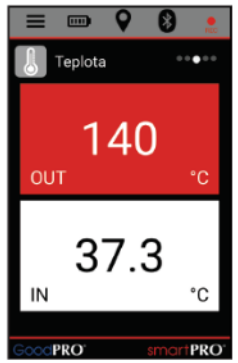
Textile dipole antenna with hybrid construction antenna

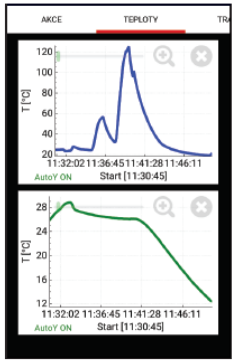
Textile bowtie antenna with hybrid construction bow-tie

*Patent **CZ 308636 B6**, „A method of making a textile-based antenna and an antenna made in this way“, 2020.*

Smart firefighter suit

- Success in the PCP tender Smart@fire for smart protective firefighter suits for Belgium, France and English firefighters.





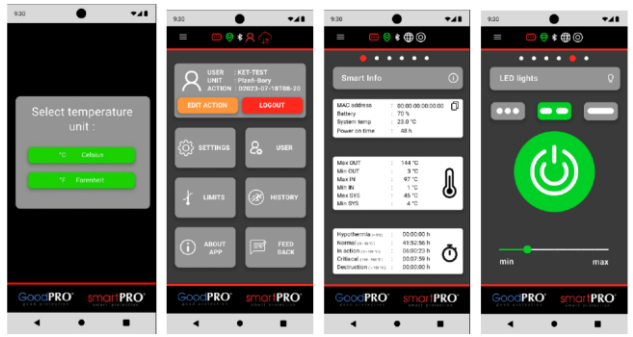
Smart firefighter suit and poncho

Commercially available on the market (GoodPRO)

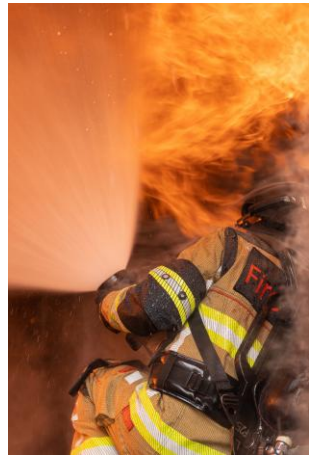
- smartPRO poncho
- smartPRO firefighter suit

Firefighter suit

Firefighter poncho



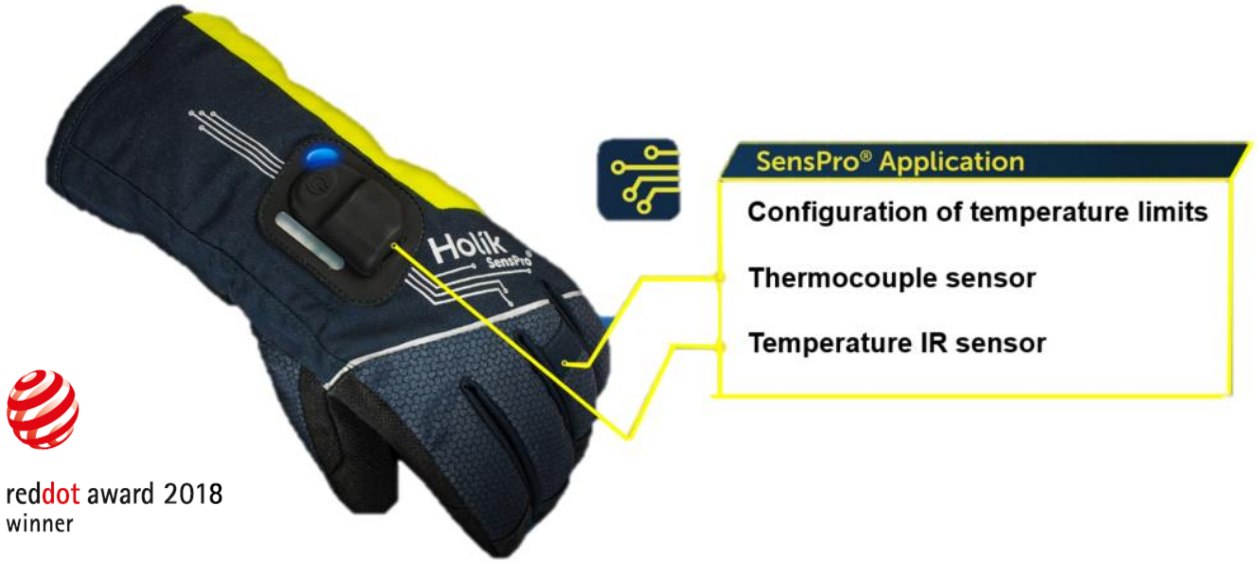
User interface of the developed application



Testing of the firefighter's poncho and suit in the Flashover Container (FOK) in Zbiroh.

Smart protective glove

- Smart protective glove SensPro® for **contactless remote temperature measurement** (in cooperation with Holik International Company).
- Certified according to explosive atmosphere standards (ATEX, IECEx), EN659, EN388, EN407).
- SensPRO application for both Android and iOS based phones.
- Introduced to the market by Holik International Company.



reddot award 2018
winner

Smart glove with integrated temperature and combustible gas sensors (concentration in % LEL)

*European Patent **EP3315037 A1**, „Protective Glove, Especially For Firefighters“, 2018.*

*Patent **CZ 308737 B6**, „Protective gloves assembly for monitoring the concentration of explosive gases and its field calibration system “, 2021.*

Smart protective boot with inertial navigation – sytem FLARE

GCU

Work gloves with integrated electronics: estimation of current position in the area (azimuth, tilt), LED navigation compass, status indicating features, multifunctional button, independent power source, wireless data transmission via radiofrequencies.

BCU

Work boots with integrated electronics: estimation of current relative position in X, Y, Z coordinates, wireless transmission of data via radiofrequencies, multifunctional button, status LED indicators and independent power source. Measured data from integrated inertial sensors and pressure sensor are processed with specially modified dead reckoning algorithm, based on which the current location data are determined.

MCU

Main Control Unit: wireless communication with BCU and GCU, wireless communication with superior cloud system, multifunctional button, status indicating features, independent power source.

CLOUD

FLARE System®
Firefighter Location and Rescue Expert

Cloud system

Cloud system with integrated backend application with following functions – processing of navigation and localisation data, calculating with implemented advanced algorithms for localisation accuracy, saving and administration of acquired data, online corrections and trajectories of users.

Frontend web based application:

Application which shows trajectories of users and other information, such as entry points, user status and status of their ILOC devices, etc., graphical user interface allowing manipulating of the whole system. Trajectory and localisation is visualised in 2D digital map.

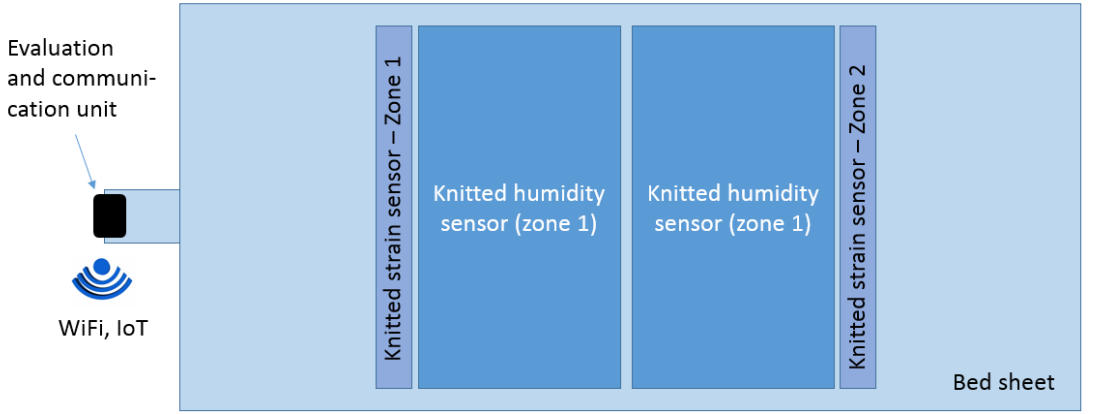
ILOC
Around the world

Holík
RICE
FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA
dune

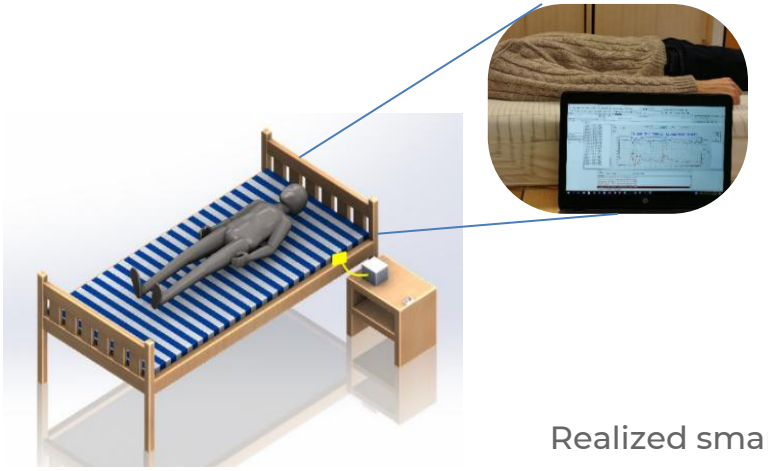
Testing of the FLARE system in in the Flashover Container (FOK) in Brno.

Smart bed sheet

- **Knitted smart bed sheet enables:**
  - Monitoring of the leakage of body fluids, excessive sweating
  - Detection presence of the patient in a bed
  - Optionally monitoring of sleep quality based on movements detection
- **Application:** convalescents, elderly people in homecare or in nursing homes etc.



Smart bed sheet – basic concept



Realized smart bed sheet

Healthcare – edema monitoring

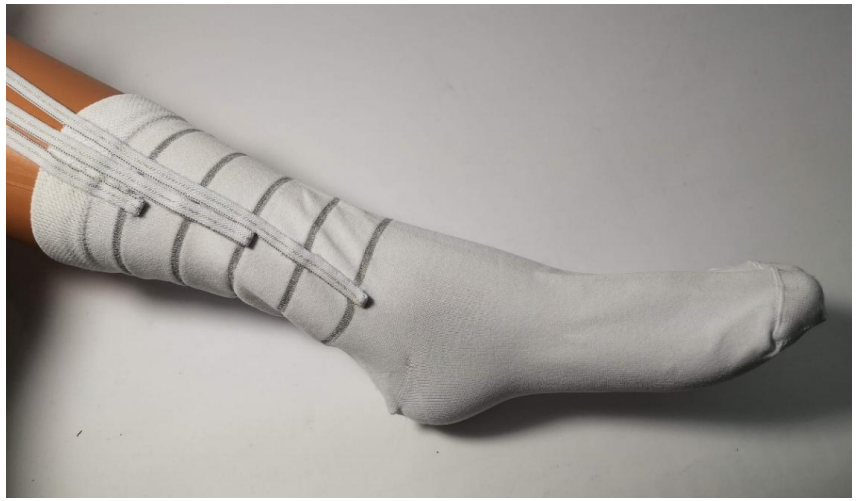
Sleeve with textile pressure sensors

- 3D textile structure
- Pressure sensors based on textil capacitors
- Evaluation of a capacity change during the change of pressure

The final functional sample of a smart sleeve for edema monitoring on the proband's leg.

Socks with textile tensile sensor

- Seamless integration of sensor threads into knitted structure.
- Developed strain sensor thread based on stapled stainless steel fibers.

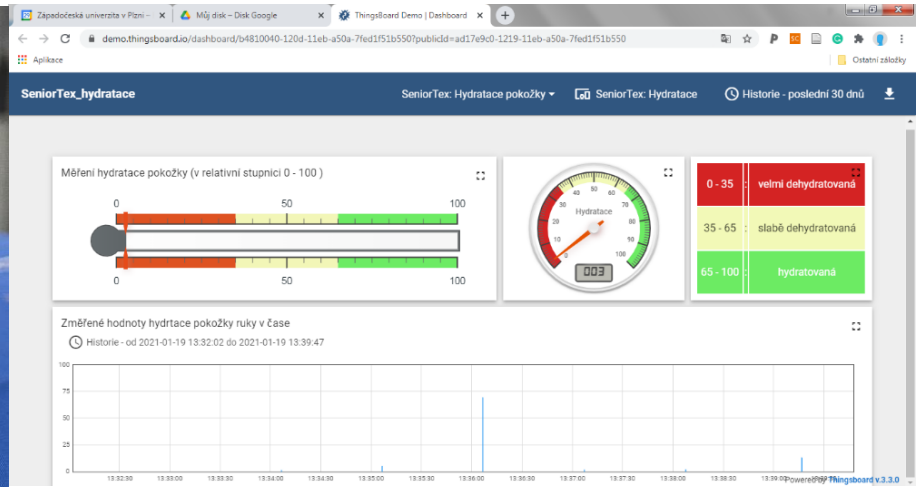


The final functional sample of a smart sock for edema monitoring on the proband's leg.

Healthcare - monitoring the condition of the skin barrier

- The solution consists of a developed sensor integrated directly into the textile sleeve designed for placement on the wrist.
- Printed electrodes based on conductive paste.
- Evaluation of the capacity change.
- A completely new solution **for long-term monitoring of skin hydration.**

Textile sleeve with integrated sensor



Determination of the skin barrier condition by the implemented system:

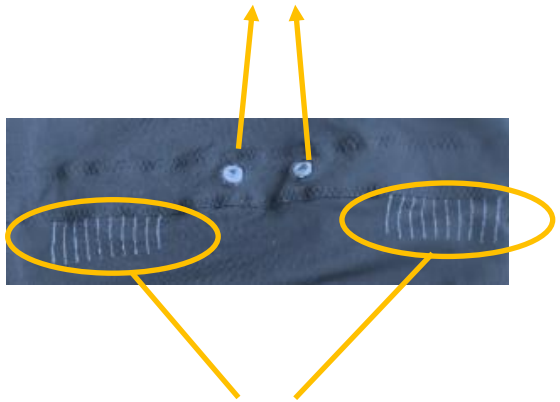
- **Very dehydrated**
- **Slightly dehydrated**
- **Hydrated**

Skin barrier monitoring system located on the wrist, evaluation and visualization software.

Healthcare – ECG, heart rate and breath monitoring

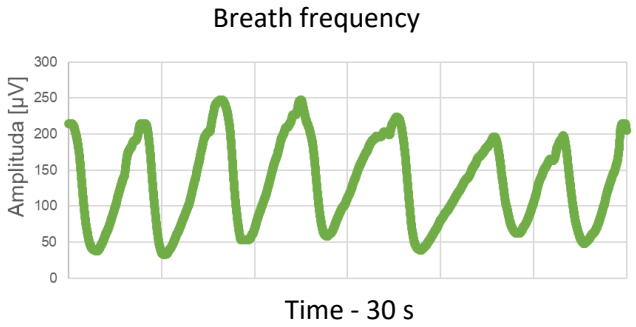
- Knitted or embroidered textile electrodes into undershirt for ECG and heart rate monitoring.
- T-shirt with integrated conductive threads for frequency and depth breath monitoring based on electrical resistance change.

Snap fasteners for connecting of the evaluation electronics.



Knitted textile electrodes.

Knitted electrodes seamlessly integrated in the functional undershirt



T-shirt with textile sensor for breath monitoring

Conclusions

Conclusion

- Electronics can be embroidered or knitted using special threads = e-textiles.
- E-textiles is a new market segment that is growing very quickly and has very good forecasts for the future.
- Applications in healthcare, sports, health protection, IoT, ...
- High-quality, stable, reliable and durable electrical contact and durable integration of electronic elements into textiles are essential for the success of e-textiles.
- Newly developed interconnection technologies should be scalable and compatible with conventional textile manufacturing.
- A limiting factor is the external batteries, which must be removed before e-textile maintenance.

FACULTY OF ELECTRICAL
ENGINEERING
UNIVERSITY OF WEST BOHEMIA

Thank you for your attention

University of West Bohemia - Faculty of Electrical Engineering
Department of Materials and Technology
E-mail: tblesi@fel.zcu.cz

KET

ket.zcu.cz