Inga Dāboliņa (editor)

SMART CLOTHING

– Survey of existing wearable technologies and needs of end-user segments

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Today the clothing industry in the EU is struggling against cheap imports from Asian countries. Production escaped to lowcost countries first from Sweden and Finland, and now the same is happening in the other Baltic Sea countries. Ergonomically designed, functional smart clothing and safe products are the competitive advantage in the competition against low priced import when trying to retain and develop business in the Baltic Sea Region (BSR). Latvia and Finland have specific knowhow in smart textiles and their applications in textiles and clothing, whereas Estonia, Latvia, Lithuania and Poland are the main producers in the Baltic Sea area. In these project industrial companies especially SMEs can benefit from the knowhow of modern scanner technology, smart clothing technology and effective supply chain management (i.e. RFID and PDM) of the universities. Transnational networks and knowhow of effective supply chains already exist between the SMEs in the BSR clothing field. However, there are possibilities in mass customization and new innovations, as well as in integrating IT technology in work wear clothing and building even more effective supply chains in the BSR.

The objective is to develop the work wear clothing business in BSR, and make it more competitive in order to resist competition from new producers and imports. The supply chain is already transnational among BSR countries in the form of design, markets and subcontracting. The project focuses on mass customization, and the possibility to integrate IT technology in work wear as well as to enhance supply chain management.

Partners involved:

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CONTENTS

INTRODUCTION

In this report, we will focus on some of the technological solutions and materials available in the market that is capable to satisfy needs of chosen end users as smart wearables in work wear. Before choosing those technological solutions several factors were considered. It includes, comfortless of the users with integrated sensors and tags, ability to withstand several washing cycles with integrated stretchable electronics technology, resistive to chemical industrial work environment, wireless connectivity to some applications or control system, compatible to extreme environmental conditions including heat, water, different toxic gases, stretchable conditions etc. Figure 1 shows the possible technological solutions in different part of work wear.

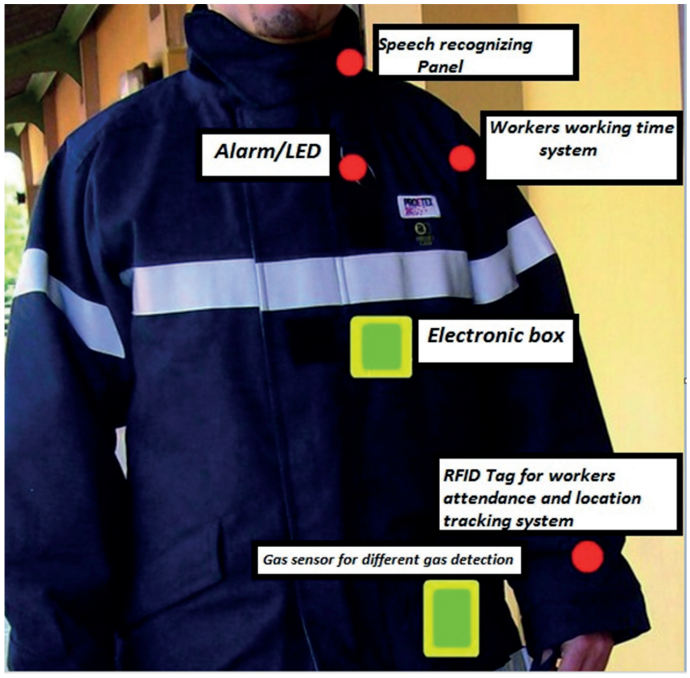


Figure 1. Possible technological solutions in different part of work wear [1]

With these many electronic and communication devices, the total weight of the equipment is large. While technology evolves and the dimensions of electrical appliances are diminishing, in addition, a number of functions are combined with one device; however, integrating electronics into textiles is an essential source of research to make the product as light, comfortable and durable as possible. In clothing, inflexible wires and cables can cause discomfort, of multiple folding can result in breaking, electrical currents interrupting the system and interrupting communication with the

base station, thus endangering human health and life, and requiring multiple power supplies. An alternative solution is electrically conductive fabrics, textile antennas and conductive yarns that provide a smaller number of power sources as well as significantly reduce the weight of the equipment [2].

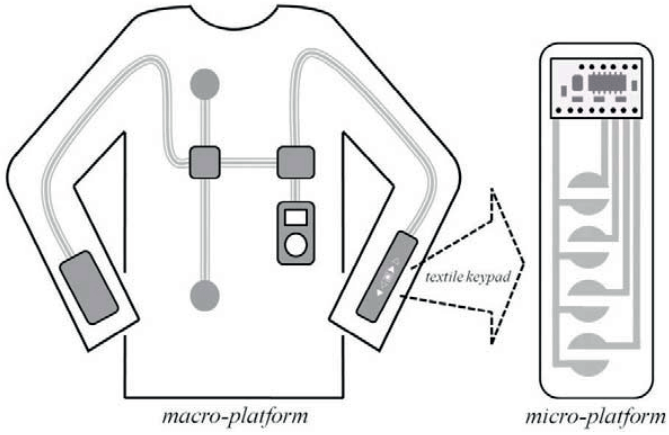
Integrating electronics in clothing so that the user does not need to perform unnecessary hand movements for mobile use is one of the main tasks [3]. The development of wearable intelligent textiles systems has changed the concept of clothing. Smart clothes make it possible not only to identify, store and transmit data about the basic values and activities of the wearer's life, and environmental parameters, but also to adapt to the wearer's needs. The introduction of intelligent textiles has revealed the need for integrated, invisible and convenient wireless communication systems in clothing [4], that are as light and wearable as possible [5].

The research reflects the techniques for integrating electronic components into textiles, collected studies on smart clothes creation, examples provided. A study was conducted on four different end-user sectors: military, chemical workers, firefighters and builders, and a description of the options for improving work clothing

1. TECHNOLOGY TO INCORPORATE ELECTRONIC COMPONENTS INTO WORK WEAR

Air and vapor permeability, comfort, electro mechanical durability, washing and chemical (i.e., detergent) resistance, and ease of deformation (bending, compression, extension etc.) are among the several requirements that need to be fulfilled when creating smart work wear. For this, there are few technologies can be incorporated to the electronic components. These technologies play vital role for embedding sensors, antennas, battery and other electronic components together into textile.

The task of an electric circuit is to connect the electrical elements to form a functional system. Electronic elements can be sensors, actuators, transistors, power supplies, etc. that are integrated into smart textiles. In order to make these products comfortable to use, flexible and multi-functional electro-textured textiles or platforms for a variety of electrical and electronic systems are used instead of hard-core as well as individual electronics. Electrotechnical platforms can be divided into two categories: a microplatform (for connections between close-up electronics) and a macroplatform (for connections between each individual subsystem in one or more products) [6]. Electrotechnical platforms are shown in fig. 2.



2.fig.Electro-textile platforms [6]

Electrochemistry can have different properties depending on their manufacturing technology.

1.1. Methods used to design electrically conductive textile platforms

1.1.1. Sewing and embroidering

Embroidered or stitched conductive thread seams are often used as connecting paths for electronics. Typically, a coated textile coating is used for embroidery, because pure metal threads are stiff and create technological problems in the sewing or embroidery process. The coated thread is easier to use in sewing and embroidery processes, but its deficiency is electrical conductivity reducing after washing. Another disadvantage is the possibility of short-circuiting between the tracks if they are too close to each other or intersect [6]. There are various sewing and embroidery machines, but when comparing closing machine sewing and closing stitch embroidery machines, both technologies use a lock stitch with stitches of different configurations (straight, zigzag stitches, etc.). Sewing is a simpler method, so it has a simpler process of work preparation. The embroidery method has a more sophisticated work preparation process (multi-stage computer processing of the object to be embroidered), but it is possible to precisely embroider any complex form. Consequently, using a computer embroidered method; it is possible to automate embroidery tracks for textile chips or components for complex electronics elements. Using the appropriate layout of the tracks, you can get an embroidered textile pattern onto a single textile base.

The thread used in the sewing process is subject to tension and rubbing, so it is necessary to use a rigid but at the same time elastic thread. Tension and friction can cause thread-breakage - outages in the fabric chains are not desirable, as fixations in the breaks in places can cause unwanted additional resistance [6].

1.1.1.1. Sewing

Stretchable fabric can provide significant advantage in textile RFID tag preparation for work wear. It is a very easy process where, tag antenna can be sewed partially (only edges) using conductive thread (Cu or Ag plated thread). The technique is to sew the edges of stretchable fabric in two round stitches through antenna pattern.

Materials:

Fabric substrate - A stretchable textile material that is a mixture of viscose and polyester.

Twill Rayon Viscose and Polyester Blend Fabric - Foshan Chaseway Textile Co., Ltd http://fabric.chaseway.cn/product/

Polyester/Viscose Blend Linen – NY fashion center, https://www.nyfashioncenterfabrics.com/collections/linen-italiano-fabric-colors

Thread- Multifilament silver-plated thread. Shieldex multifilament thread 110f34 dtex 2-ply HC: http://www.shieldextrading.net/products/yarns-threads/

Tag Chip - NXP UCODE G2iL series RFID IC. Can be attached by sewing or using conductive glue.

NXP UCODE G2iL chip: http://www.nxp.com

IC Copper Pads – A fixture copper pads to the antennas by embroidering one round of contour under them and then one round on top of them with the conductive yarn during antenna fabrication. It makes the bridge between IC chip and antenna connection.

Adhesive – Conductive epoxy for attaching copper IC chip pads with antenna.

Conductive Adhesive, Epoxy, Syringe, Silver CW 2400 http://uk.farnell.com/circuitworks/cw2400/epoxy-silver-conductive-syringe/dp/604057

Another method is making RFID antenna from electro textile materials cutting. The type of textile can be silver-coated conductive fabric.

Materials:

Fabric substrate - Silver coated fabric, Conductive fabric.

EeonTex Conductive Stretchable Fabric - https://www.sparkfun.com/products/14112

Silver coated conductive fabric - https://www.kitronik.co.uk/2717-conductive-fabric-stretch.html

Conductive yarn – Shieldex multifilament thread 110f34 dtex 2-ply HC: http://www.shieldextrading.net/products/yarns-threads/

Textronics yarn - http://www.textronicsinc.com/products

Stainless Thin Conductive Yarn: https://www.adafruit.com/product/603

IC Chip – Attached by embroidering. NXP UCODE G2iL

NXP UCODE G2iL chip: http://www.nxp.com

Adhesive – Conductive epoxy for attaching IC.

Conductive Adhesive, Epoxy, Syringe, Silver CW 2400 http://uk.farnell.com/circuitworks/cw2400/epoxy-silver-conductive-syringe/dp/604057

IC pad - A fixture (copper on a plastic film) with 3 x 3 mm2 pads for easier attachment. Attached by embroidering cross over them.

1.1.1.2. Embroidering

Embroidery with washable conductive thread provides textile integrable antennas for RFID tags. By following this method, using dipole as the type of antenna 5 to 7 meters should be the read range and it has the ability to give effective conductivity from different embroidery pattern. The conductivity also changes due to the change in sewing pattern and stitch density.

Materials:

Computer-aided sewing machine for antenna sewing process:

Husqvarna VIKING - http://www.husqvarnaviking.com

Conductive threads can be copper or silver coated electro conductive thread.

Shieldex multifilament thread

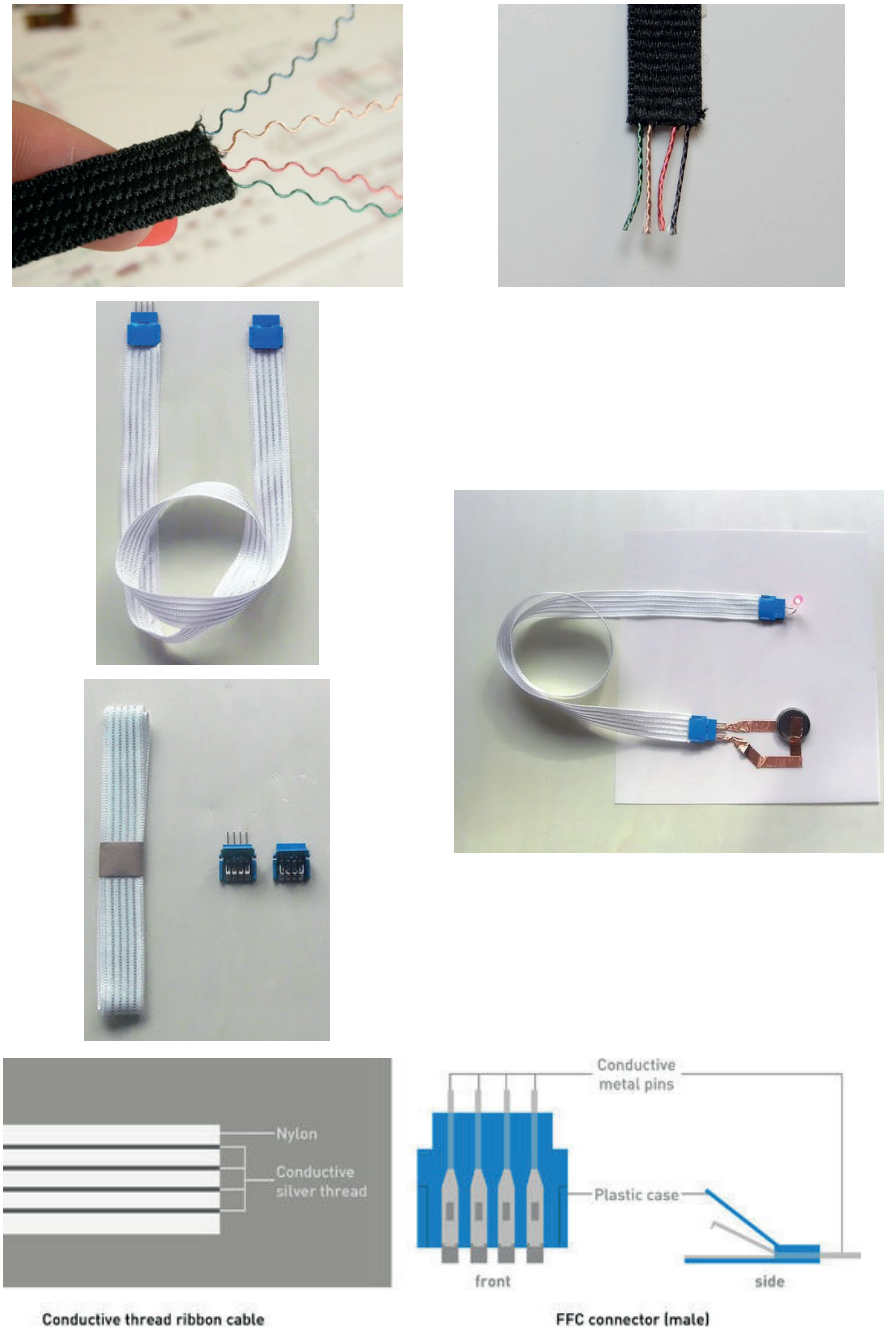
110f34 dtex 2-ply HC - http://www.shieldextrading.net/products/yarns-threads/

Stainless Thin Conductive Yarn - https://www.adafruit.com/product/603

Textronics yarn - http://www.textronicsinc.com/products

1.1.2. Weaving

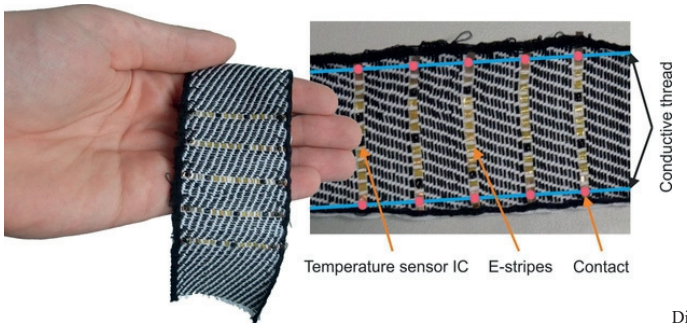
The fabric is made up of two or more systems of warp and weft threads interconnected in a certain order. The warps are arranged along the length of the fabric, but the weft - width of the fabric. The texture of the fabric depends on the placement of warp and cloth threads and their interplay. In order to obtain a fabric with certain properties, it is necessary to choose the appropriate braid article with the appropriate warp and fabric thread layout [7]. In weld metal, textile yarns or electrically conductive yarns are used as electrical signal controls that can be inserted into the fabric structure, alone or in combination with non-conducting yarns, parallel to each other in the direction of tissue or warp, and in both directions at the same time. One of the usages is the weaving of tape or textile cable by placing several parallel conductive threads in the fabric, among which there are textile insulating threads [6]. The textile cable is to be used as circuit interconnects (3.fig.).



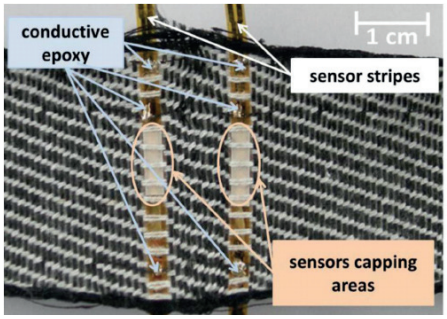
3.fig. Electro-Textiles [8][9][10][11]

A woven fabric can form a complex network using it as a complex electrical circuit with multiple electrically conductive and insulating components and structuring it in multiple layers and partitioned areas for the appropriate placement of electronic

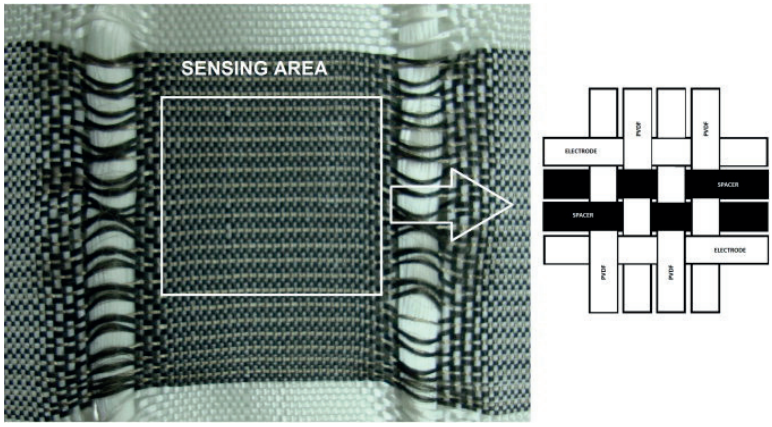
components [12]. For example, interweaving the 1 mm wide flexible strips with humidity and temperature sensors into a specific fabric, a moisture and temperature control system for textile sensors was created [13]. Another study created a textile inverter chain by breaking down three groups of threads: textile insulating yarn, conductive yarns and transistor yarn with a contact surface (2 mm wide) [14]. Examples shown in 4.fig.



Digital temperature sensors are woven into a textile to make smart temperature sensing textiles (Photo: Swiss Federal Institute of Technology Zürich, Electronics Laboratory - Wearable Computing) http://iecetech.org/issue/2016-07/Sensor-networks-wearable-printed-electronics-and-AAL



Picture of a textile containing the woven sensors realized on polyimide stripes. The epoxy drops indicated in the picture are used in order to connect the devices with conductive yarns woven perpendicularly with respect to the sensor stripes. Such conductive yarns are not visible in the picture, since they are hidden by the black cotton yarns that compose the textile. https://www.researchgate.net/publication/260508377_Woven_Temperature_and_Humidity_Sensors_on_Flexible_Plastic_Substrates_for_E-Textile_Applications



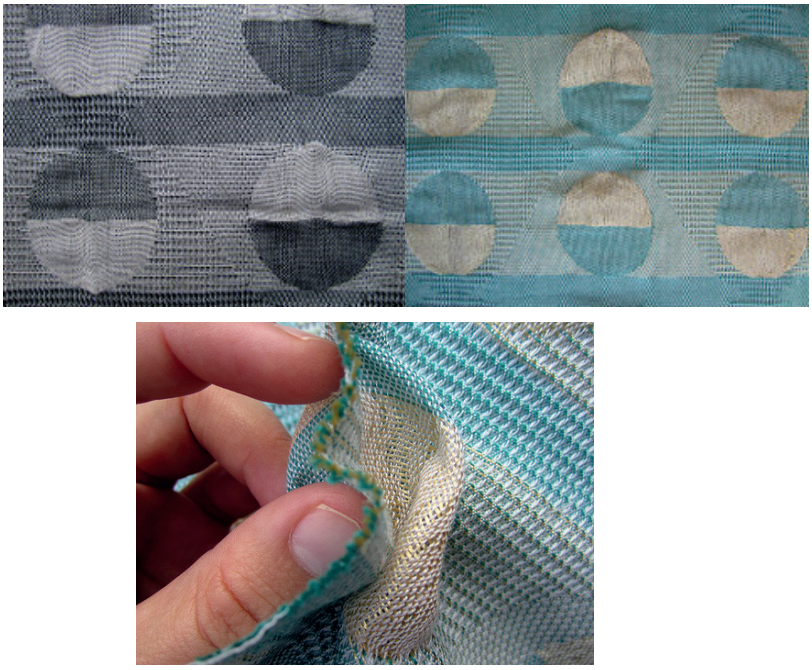
Configuration of the 2D flexible piezoelectric woven sensor. The sensing area is highlighted in the middle. The polyester and PVDF yarns are white; the nylon spacer yarns are black. The weave structure in that area is highlighted on the right hand side. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
https://www.researchgate.net/publication/249963363_Effect_of_drawing_on_the_molecular_orientation_and_polymorphism_of_melt-spun_polyvinylidene_fluoride_fibers_Toward_the_development_of_piezoelectric_force_sensors/figures?lo=1

4.fig. Weaved electronic patterns [15][16][17]

The use of multi-layer cloth design methods results in the production of electroactive woven wires with welded conductive yarns in tissue and warp directions that are isolated from each other at the intersection [18][19][20][21].

By designing more sophisticated textiles, the location of conductive threads in electro-textile can be controlled using a jacquard weaving system, which allows each thread to be individually positioned by determining the order of the wickedness of the thread [22]. *Dhawan* etc. in publication [23] describes the design of a wired electric conductive system by cutting the conductive threads in the respective areas. Electronic components are added to this system, forming a flexible board with individual contact joints.

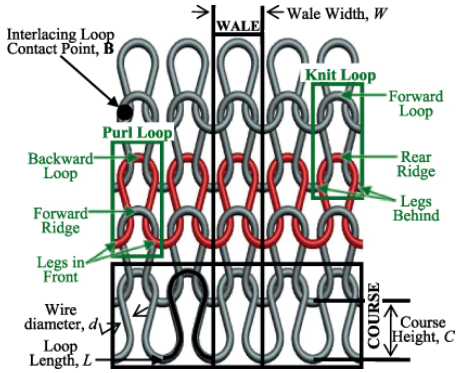
By a similar method *Worbin* etc. [24] developed jacquard electrodelectric fabric with individual electric conducting areas. Electro-conductive yarns woven in the fabric make up the lintel of the fabric on the left or right side. When cutting a tissue adhesive connection on one or the other side of the fabric, the patterned areas on the opposite side of the fabric can function as individual conductive surfaces. The fabric is visible in 5.fig.



5.fig. Electrically conducting fabric with individual conductive areas [24]

1.1.3. Knitting

The knit is made up of interconnected loops. Depending on the knitting technique, the cross-over and projection warp is determined. The longitudinal wool with a total of electrically conductive and non conductive yarns is visible 5.fig. In the case of conductive fabrics, the total electrical resistance value is comprised of two types of electrical resistance: length-dependent resistance and loop contact resistance. The length-dependent resistance is directly proportional to the length of the yarn, while the contact resistance is opposite to the contact force of the contractile conductive yarn [25]. The knit has a flexible structure, so knitted conductive fabrics can be used for measurements related to reverse strain. For example, sensor measurements are based on changes in the electrical resistance of a cloth after stretching. Zhang etc. [26] He created a model based on the structure of the prominent fabric (6.fig.). When the electric current is fed, the cloth acts as an electric conductor, which changes its electrical resistance, depending on the applied load size. Electrical circuit simulation is visible 7.fig., which includes two contact resistors (RC) and three length dependent resistors (RL), which are attributable to the contact load of the threaded thread and to the electrical resistance characteristic to the thread.



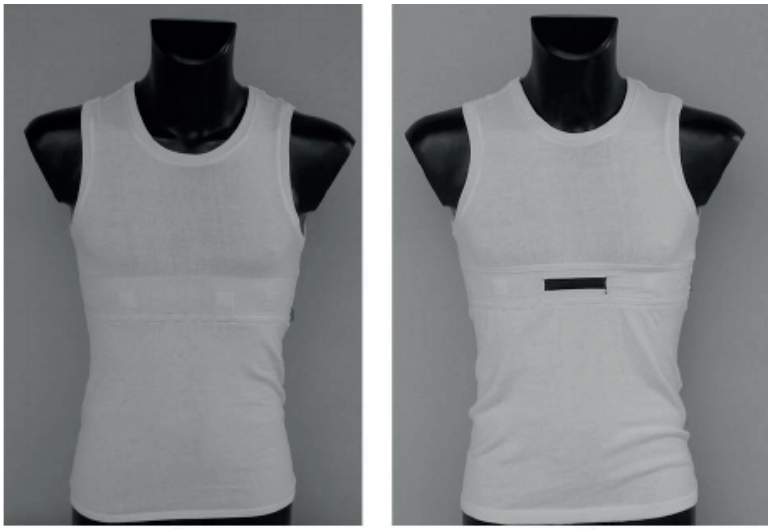
6.fig. Knitted structure [27]

7.fig. Electro-stimulation of knitted structure [28]

The knit fabric structure is used to design a textile tension or deformation sensor in the field of health to measure different physiological and biomechanical signals. For example, a knitted sensor can act as an indicator of respiratory rate, indicating its operation with electrical resistance changes as an extension function [29]. The tensile sensor can be used as a sensor for positioning movement of the body [30]. Another example of using a knitted structure is the design of an electrocardiogram (ECG) for controlling heart activity [31]. Tension sensor and breathing control clothing are shown in fig. 8.

Knitted system for the acquisition of abdominal and thoracic respiratory activity https://www.researchgate.net/publication/224703744_Sensing_Fabrics_for_Monitoring_Physiological_and_Biomechanical_Variables_E-textile_solutions/figures?lo=1

http://yourfablife.com/smart-wear-workout-shirt-tracks-fitness-metrics-electrodes/



https://www.researchgate.net/publication/224293141_Flat_Knitted_Sensors_for_Respiration_Monitoring/figures

http://www.talk2myshirt.com/blog/archives/2910

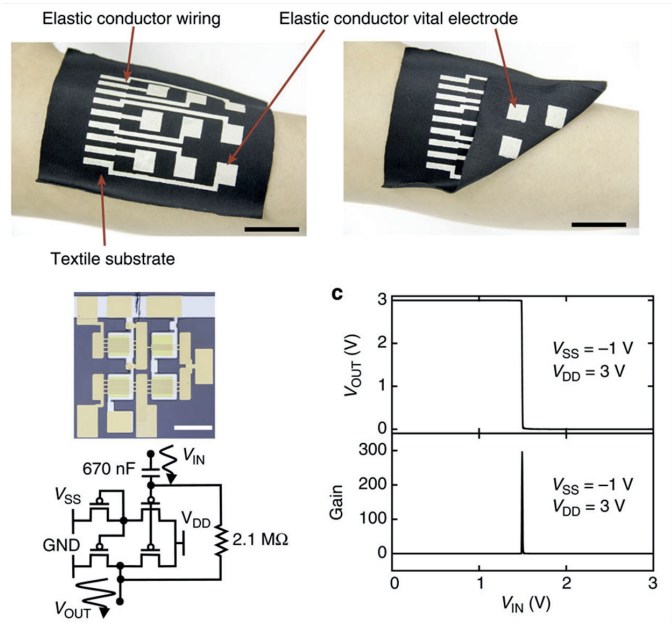
8.fig. Knitted sensors - tensile sensors, breathing control clothing [29][32][33][34][35]

Since the knitting is made of loops and the thread is folded, such a fabric structure does not fit brittle threads because they can break (snap) due to deformation in the knitting process. Knitting may also be associated with abrasion resistance in areas where the thread is subject to increased friction. In this case, the knitting speed should be reduced [36].

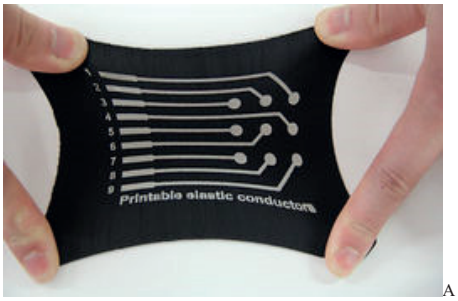
1.1.4. Printing

Different printing techniques, such as silkscreen, intaglio printing, inkjet printing, or flexography, are used to create textile patterns [37]. Creating an electric circuit with inkjet printing is the simplest way to design a plate. It can also be applied

to widespread use. Conductive ink or paste is obtained by mixing metal or carbon particles with the base material, but it is often difficult to obtain ink or high-capacity electrical conductivity. By increasing the amount of particulate material in the mixture, the paste becomes more difficult to tie with the fabric. Despite this, in a number of studies, good-electrode printing, for example, the electrical impedance of silver ink printing at a layer thickness of 25 μm is 0.01-0.04 Ω / m2 [37]; in another study, the print electrical resistance at a layer thickness of 43 μm is 2 , 1 - 6.8 Ω / 6cm[38]. Unfortunately, the printed surfaces are not resistant to physical changes. As a result of tensile printing, cracking may occur that stops conducting electricity, so it is not advisable to use elastic cloths on the printed plate technique. Cracks can also occur due to the structure of the ink or paste - if it is solid, it can crack as a result of bending of the fabric [6]. Conductive ink can be used for low-power control elements, low-voltage components where high current does not flow. They should not be used in connections requiring high precision. Examples of textile electronics elements created with the printing technique are visible 9.fig.



https://www.digitaltrends.com/wearables/conducive-ink-screen-print-smart-clothing/



A circuit printed on a flexible textile using University of Tokyo's electricity conducting ink. https://blogs.wsj.com/japanrealtime/2015/06/26/univ-of-tokyo-researchers-develop-electricity-conducting-ink/

9.fig. Printed textile electronic elements [39][40][41]

1.1.4.1. Screen-printing

It is RFID Tag antennas manufacturing method from silver-plated stretchable fabric. Also, Screen-printing on polymer thick film (PTF) silver ink on stretchable, non-conductive fabric is another manufacturing method for RFID tag antennas. Screen-printing of conductive ink is also effective to heat laminated stretchable TPU or PDMS. Printed conductive can be encapsulated by second layer of lamination on it. In this process, ink passes through a screen (a fabric mesh of threads) onto the substrate with a squeegee. Non-image areas of the screen mesh blocks out with a stencil and in the image areas, it is important to keep screen open.

Materials:

Ink: one-component silver ink consisting of polyester resin and silver particles. Silver content is 60–65 wt % and polyester resin content is 11–14 wt %. Silver PTF ink.

Conductive silver ink: http://www.creativematerials.com/products/silver-inks/

CI-1036 Silver ink: http://www.conductives.com/new_products.php

Du pont - http://www.dupont.com/

Antenna type: T matched dipole.

IC: NXP UCODE G2iL connection using conductive epoxy.

NXP UCODE G2iL chip: http://www.nxp.com

CW2400 conductive epoxy: https://www.chemtronics.com/circuitworks-conductive-epoxy-2

Rigidification of Textile around IC attachment using textile glue.

UHU textile glue: http://www.uhu.com

1.1.4.2. Inkjet printing

In this method, Ink jet printer prints polymer composites containing Nano silver particles in order to obtain a line or tag antennas or contacts in electronic assembly.

Materials:

Inkjet printer: DMP-2831™ Dimatix printer

Fujifilm Dimatix Inc., Santa Clara, CA, USA - http://www.fujifilmusa.com

Substrate: Polyethylene naphthalate (PEN)

Teonex® Q65H from Teijin DuPont Films Japan Limited, Tokyo, Japan - http://www.teijindupontfilms.jp/english/

Silver ink:

DGP 40LT-15C Silver Jet Ink - http://anapro.com/eng/product/silver_inkjet_ink.html

The non-printed elements attachment to the tag with conductive resin.

H20E Epoxy Technology, Inc., Billerica, MA, USA – http://www.epotek.com/site/

A 50 µm-thick dry adhesive, for the chip assembly.

AR Clear 8932, Adhesives Research, Inc. Glen Rock, Pennsylvania, USA - http://www.adhesivesresearch.com/technologies/optically-clear-adhesives/

Silicon RFID chip SL900A RFID chip from AMS AG, Unterpremstaetten, Austria - http://ams.com/eng/Products/Wireless-Connectivity/Sensor-Tags-Interfaces/SL900A

1.1.4.3. 3D printing

Graphene based 3D printed Antennas for Textile RFID Tags: It is possible to 3D print passive UHF RFID antenna on top of textile substrate directly. In this method, graphene based conducive filament can be used to print the antenna. IC chip attaching is a one-step process inserting IC chip in earlier step and depositing the ink. Pausing the printing at a certain moment and depositing ink on top of chip is another possible solution for chip attachment. This step will remove the use of conductive gluing step to connect IC chip with antenna. This type of 3D printed antenna should have the similar reading range (6-8 meters) like other printed tags. It will also be washable and mechanical resistant for using in work wear.

Conductive filament:

Conductive Flexible TPU Filament: https://graphene-supermarket.com/Conductive-Flexible-TPU-Filament.html

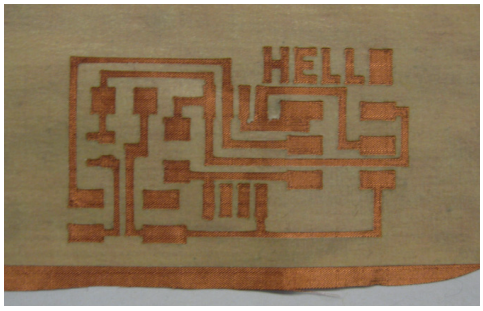
Conductive Graphene PLA filament: https://www.blackmagic3d.com/Conductive-p/grphn-pla.htm

IC chip: NXP UCODE G2iL.

NXP UCODE G2iL chip: http://www.nxp.com

1.1.5. Mordanting

Corrosion is one of the technologies most commonly used in the manufacture of traditional hard-core (PCB). Typically, a surface coated with conductive material (for example, copper), is applied to the necessary circuit diagram of the configuration and the excess solution is removed from the uncovered surface using an etching solution. Silk screen printing can be used to apply a pattern to the mask, but in this case it is difficult to precisely obtain fine elements. Another technique for producing a circuit is a photoresist that is light sensitive (usually in the UV spectrum). Production of plates with photoresist method takes place in 4 stages: plate preparation, illumination, development and mordanting [42]. Textile material has a weak resistance to chemicals used in the mordanting process, so other plate preparation and mordanting materials should be selected. For the manufacture of textile wafers, the picture protector of the circuit can be used, for example, as a Vaseline, but as a mordanting solution - salt and vinegar mixture. It should be taken into account that the image of the texture shield must be covered on both sides [43]. The mordanting textile scheme is visible 10.fig.

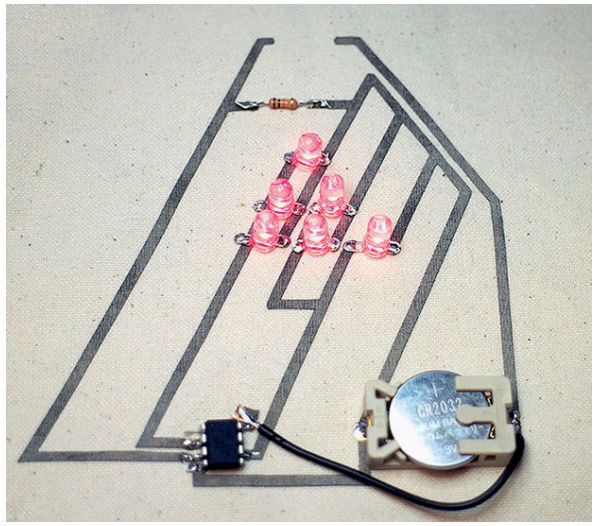


https://www.flickr.com/photos/plusea/sets/72157623861855224/

10.fig.Mordanted textile scheme [43][44][45]

1.1.6. Lamination

Lamination is the bonding of two or more materials using glue, heat treatment and pressure [46]. You can use an electrically conductive cloth to create a pattern, on one side, with a paper adhesive network. After the circuit is cut out, the paper is removed from the areas of the circuit that need to be attached to the surface of the textile and the two layers are connected by heat treatment (with an iron or a press). The pattern can be cut manually, but it is difficult to precisely cut out the fine shape. For this purpose, laser cutting is required, which can create a precise circuit configuration. Example is visable in 11.fig. Multi-layered circuits can be used with an insulating layer, but it should be noted that the thickness of the circuit will increase and flexibility will decrease. The joints need to be isolated to ensure that the circuit is durable [47].

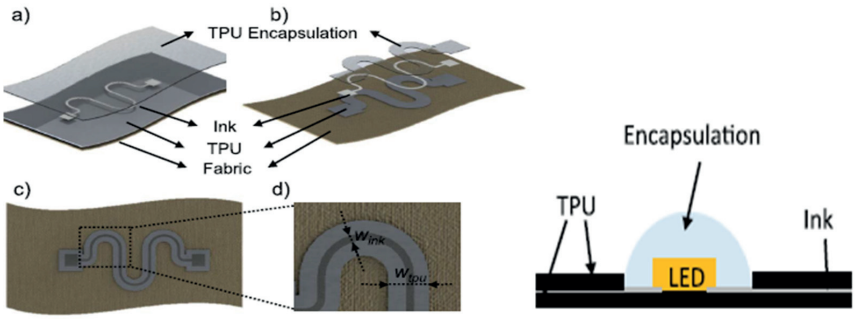


http://www.instructables.com/id/CNC-Conductive-Fabric-Circuit/

11.fig. Laminated scheme [47][48][49]

It is feasible to integrate multilayer stretchable RFID on a knit fabric by printing conductive inks on laminated films. There are different polymer materials suitable for heat lamination onto knit fabric. Another layer of polymer films helps to provide encapsulation and a multilayer stretchable structure for the completely integrated system [50]. TPU (thermoplastic polyurethane), Epoxy resin and PDMS (Polydimethylsiloxane) are the most effective polymer materials in this process. Some research work has already done on this technology, which focuses on design and optimization of printed conductive circuits with heat lamination process using TPU as

stretchable platform [50]. Figure below shows the Multilayer stretchable circuit concept on fabric.



12.att.Multilayer stretchable circuit concept on fabric [50]

Encapsulation layer in this process can provide the water resistant properties. The devious stretchable printed line proves the stretch ability of over 100% strain and fatigue life of 1000 cycles at 20% strain. Washing endurance of 100 cycles has reported in this article. Figure below shows conductive LED and ECG interconnect circuits laminated on shirt.

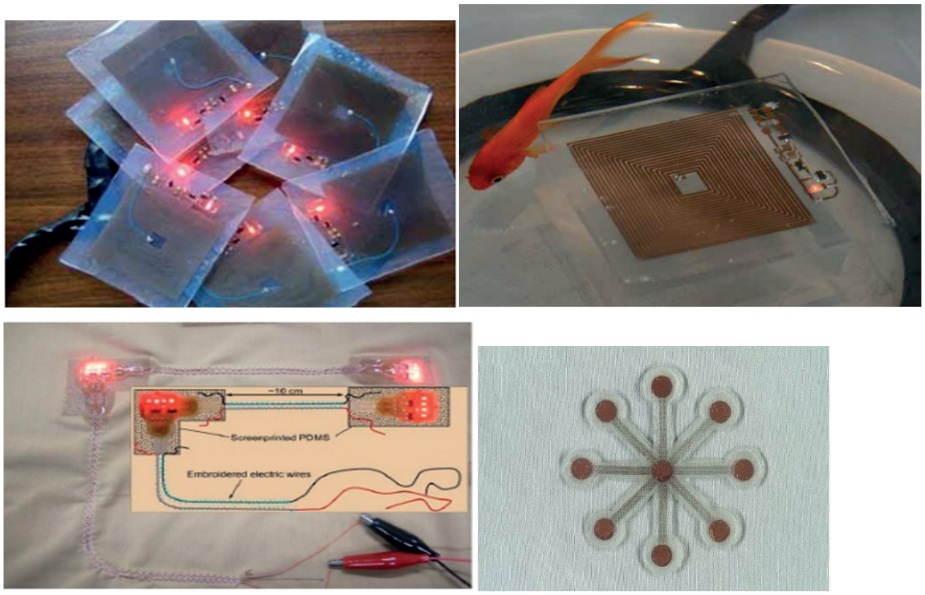
13.att.Conductive LED and ECG interconnect circuits laminated on shirt [50]

Thermoplastic polyurethane (TPU) manufactures:

- Dureflex® - http://www.films.covestro.com/en/Products/Dureflex
- Hotmelt TPU Film - www.sambufc.com/en/product-2/tpu-film/
- Lubrizol thermoplastic polyurethanes (TPUs) - www.lubrizol.com
- Texin® (liquid) - http://www.tpu.covestro.com/en/Products/Texin
- GOLDTHANE® TPU (liquid) - http://www.sunyangtpu.com/

In another previous work, named “stretchable and washable electronics for embedding in textiles” stretchable wiring onto elastic substrates integration reported using different electronic components. In this work, PDMS (Polydimethylsiloxane) produced the lamination membrane [51]. Little or no stretchable electronic components

inside flexible PDMS platform were able to overcome main technological challenges related to stretching, washing and water resisting the device. Figure below shows some PDMS laminated circuits integrated in this work.



14.fig.PDMS laminated circuits integration [50]

Polydimethylsiloxane (PDMS) manufacturers:

- SSP-M823 Thin PDMS Membranes - http://www.sspinc.com/products/SSP-M823_21_product.htm
- Silicone pdms membrane: http://www.interstatesp.com
- Liquid PDMS: https://www.sigmaaldrich.com/finland.html

Epoxy compounds are also effective in protecting electrical and electronic compounds from different environmental stresses. It is also applicable for providing dielectric properties, electrical insulation resistance, thermal conductivity, thermal shock resistance, mechanical strength, adhesion, hardness, chemical resistance etc.

Epoxy manufacturers:

- Araldite® 506 epoxy resin - http://www.sigmaaldrich.com
- ALCHEMIX EP4400 - https://www.alchemie.com/resin-for-electronics.html
- Encapsulation and potting epoxy resins - http://www.unitedresin.com/encapsulating-potting-epoxy-resins.html

- Adhesives and encapsulants for electronics and microelectronics assemble in textile:
- Electrically conductive adhesives: http://www.zymet.com/index.php
- Double-sided adhesive tape / waterproof for electronic material Permatex® 85120: http://www.directindustry.com/prod/permatex/product-25365-1008621.html

1.1.7. Embedding RFID chip in yarn

RFID chip embedding in yarn is one of the new technological solutions, which can be included in this project. This technology is E thread technology. It consists of two conductive yarn and Ultra high frequency RFID chip. Conductive yarns of some specific length can provide the antenna for RFID tags. The method is to integrate one very small IC chip between the two yarns from opposite sides. Later, this IC integrated thread embeds into industrial work wear. The chip is so small that, it is nearly impossible to identify the RFID chip once the thread is inside garments. This is also very useful to use for security purpose. It is washable and mechanically stable in stretching or bending. It has the ability to provide immediate response during real time tracking.

Materials:

Conductive threads can be copper or silver coated electro conductive thread.

Shieldex multifilament thread

110f34 dtex 2-ply HC - http://www.shieldextrading.net/products/yarns-threads/

Stainless Thin Conductive Yarn - https://www.adafruit.com/product/603

Textronics yarn - http://www.textronicsinc.com/products

IC Chip – Attached by conductive epoxy or some other conductive adhesives.

Adhesive – Conductive epoxy for attaching IC.

Conductive Adhesive, Epoxy, Syringe, Silver CW 2400

http://uk.farnell.com/circuitworks/cw2400/epoxy-silver-conductive-syringe/dp/604057

NXP UCODE G2iL chip: http://www.nxp.com

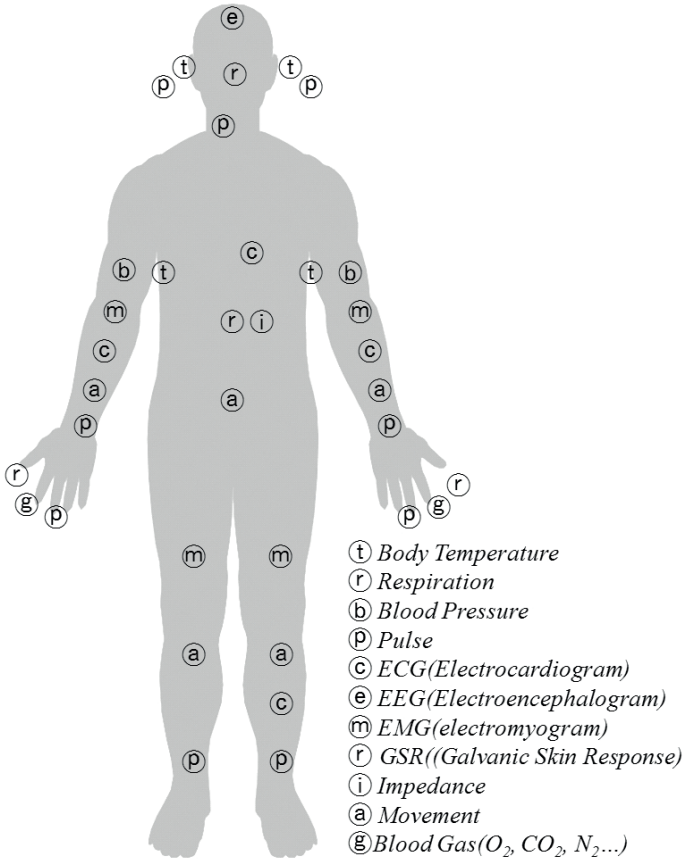
Impinj chip: https://www.impinj.com/

1.2. Textile sensors and switches

The process of transforming one form of energy into another is called transduction. The sensor converts some physical property into another form that can be interpreted by an electrical circuit. The textile sensor consists of a series of electrically conductive and non conductive material layers that can be interconnected using the technology described above for the electrical circuitry of the textile. Following the signal perception (input interface), intelligent textile design sensors can be divided into two large groups: biomedical signals and ambient signals [6]. A part of sensor can be designed as a multi-thread fabric using only conductive and non conductive textile materials. Other sensors can not be completely replaced by textiles, so it's important to think about how to integrate them so that they are firmly attached to the cloth, to provide excellent signal driving characteristics, and to fit the wearing comfort of the product.

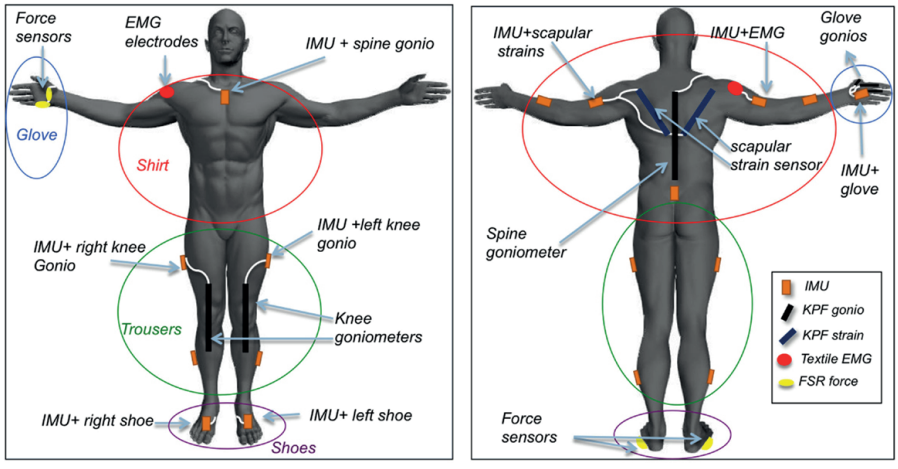
1.2.1. Measurement of electrode biomedical signals

Since clothing is the object closest to human skin for almost 24 hours a day, it is the best platform for measuring a biomedical signal without disturbing the wearer. Types of signal and their measurement locations on the human body are shown in 15.fig.

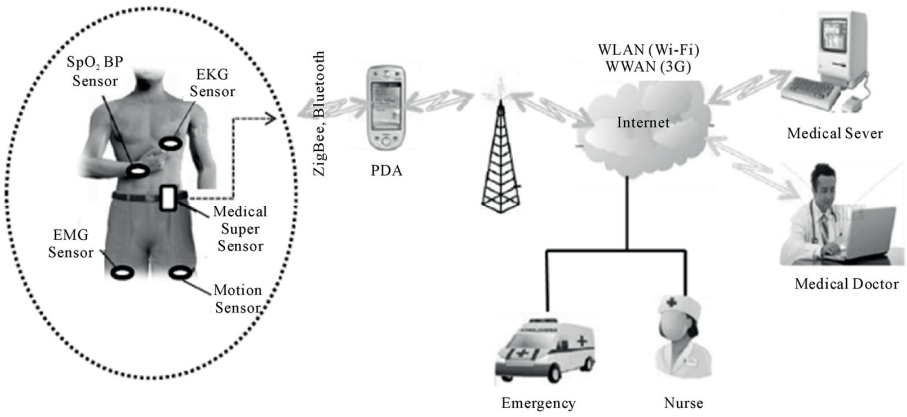


https://www.researchgate.net/publication/309014700_Electro-Textile_Interfaces_Textile-Based_Sensors_and_Actuators/figures

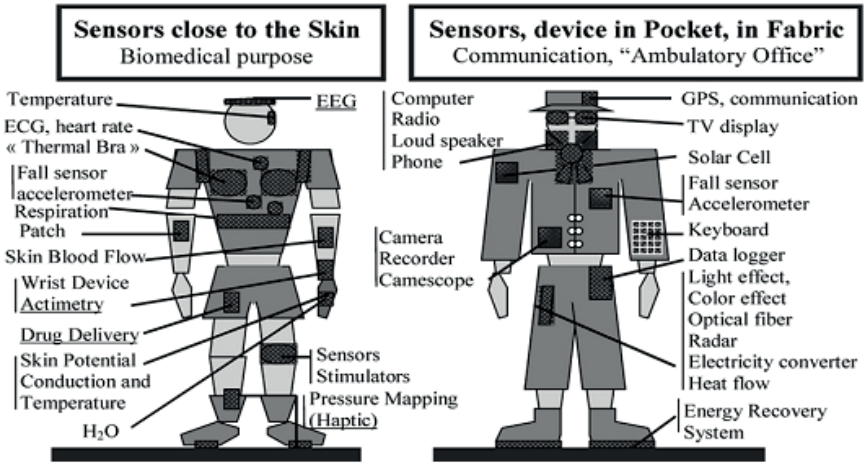
Biomedical signals that can be measured from the human body



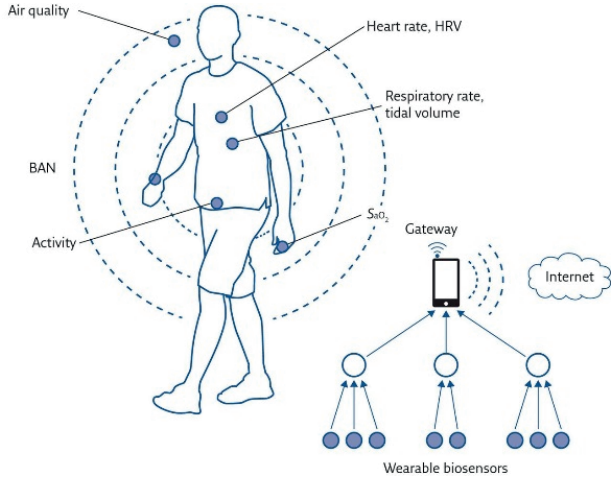
http://www.frontiersin.org/files/Articles/172596/fbioe-04-00028-HTML/image_m/fbioe-04-00028-g001.jpg



http://file.scirp.org/Html/2-4200006/56295d46-a41f-4fb9-9c96-b3bd2516e899.jpg



https://tectexntu.wordpress.com/2010/02/11/introduction/



http://breathe.ersjournals.com/content/13/2/e27

15.fig. Types of signal and their measurement points on the human body [6][52][53][54][55][56]

EMG, ECG, EEG and GSR are the most commonly used biomedical signals, which are usually measured by electrodes. Hospitals use disposable electrodes to measure these biomedical signals. A gel is used between the electrodes to keep them on the skin and reduce electrical resistance. Wet electrodes can cause skin irritation and discomfort. There are also dry and capacitive bonding electrodes (*capacitive-coupled*) when there is no need to use gel between them.

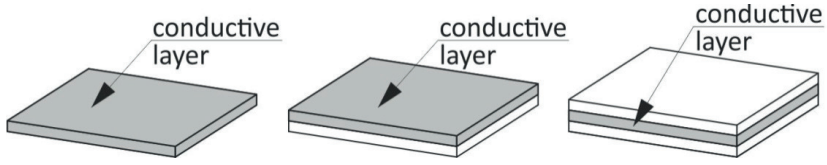
Textile electrodes can be made of different types of conductive materials: conductive rubber, silver-plated polymer coats, metal coated fabrics, and fabrics with inserted or assembled conductive yarns. Electrodes can even absorb very small voltages

in different parts of the body, such as the heart. Electrode materials, their advantages and disadvantages are summarized **1**.table.

1.Table Electrode materials [6]

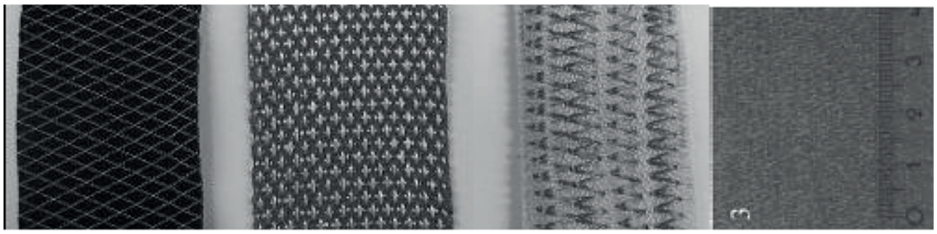
Materials	Advantages	Disadvantages
Electric conductive rubber	High conductivity Cheap, Easily customized shape	Medium flexibility Low air and fluid permeability
Polymer foam with metal particle coating	High conductivity Easily customizes shape, elastic	Low resistance to washing, metal oxidation
Fabric with metal particle coatings	Textile material, high conductivity	Low resistance to washing, metal oxidation
Fabric with metal particle coatings	Textile material, high conductivity	Low resistance to washing, metal oxidation
Stainless steel yarn	High conductivity	It is difficult to apply to the sewing process, metal oxidation, skin irritation
Conductive ink	High conductivity	At tension can flaw

Some intelligent textiles feature multiple or three-dimensional structures, such as data transmission structures, textile pressure sensors or biophysiological measurement systems. The simplest of these are data management structures, in 16.picture show their principles. In the first case there is one leading layer, unprotected from both sides; in the second case there is a double construction, the material is conductive on one side, the other side is protected; the third case is protected by both parties [57].



16.fig. Data management structures

When developing a sensor that is close to the skin, good yarns should be selected, but they must also be sufficiently fine and smooth to prevent skin irritation. Electrode insulation should also be provided. Using a tubular twill knitting technique, a dual electrode can be created which is made up of an electric conductive knit against the inside of the scraped material, while the outside of the material is made of traditional textile yarn that serves as an electrode insulator [58]. Some textile electrodes are shown in 17.fig.



Textile electrode, fabricated by knitting (a) weaving (b) embroidery (c) and non-weaving (d) methods. https://www.researchgate.net/publication/233327050_Textile-structured_electrodes_for_electrocardiogram/figures?lo=1

Garment-based printable electrodes http://www.kurzweilai.net/smart-clothes-for-personalized-cooling-and-heating

http://thefutureofthings.com/6539-philips-new-health-monitoring-system/

17.fig. Textile electrodes [59][60][61][62][63]

The electrodes for breathing cycles are integrated into the chest, tight-fitting undercoat, face mask, etc. textiles or accessories. Some examples of respiratory monitoring systems:

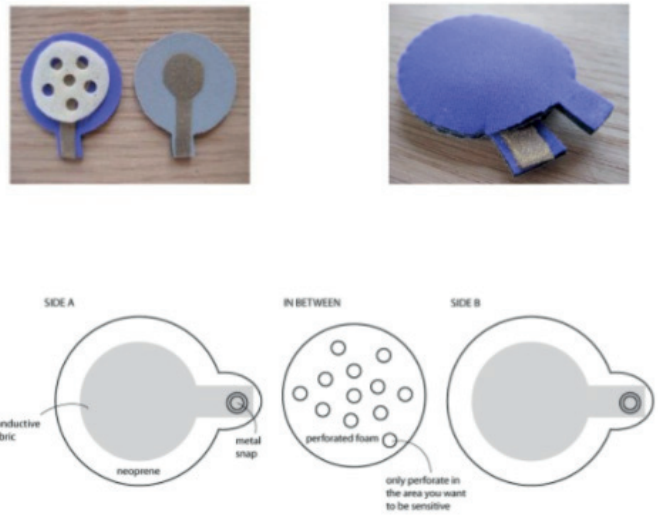
- Chest strap (bandage) with high-performance accelerometers (capacitive MEMS) and electromechanical pressure sensors that determine the movement of the diaphragm;
- Chest belt (bandage) with piezoelectric or tensometric sensors measured during the breathing of the chest, thus watching the breathing cycle;
- Face mask with a temperature sensor that captures airflow [64].

1.2.2. Pressure sensitive sensors

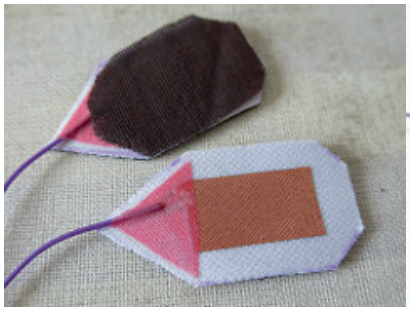
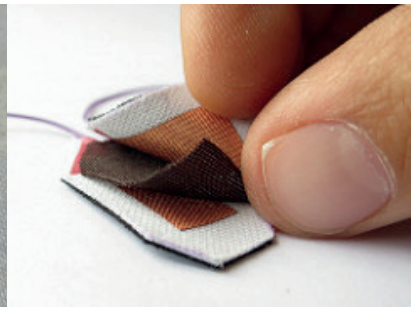
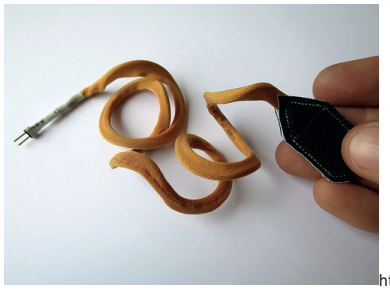
Pressure sensitive sensors, depending on their type, are often used both in biometric measurements and as an ambient signal. Sensors are divided:

- Mechanical;
- Piezoristic;
- Capacitive.

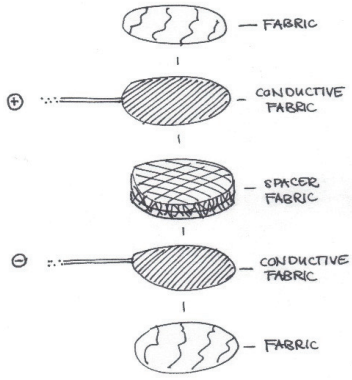
Mechanical pressure sensitive sensors are designed by planning a circuit with a breakage point. The fracture point is the place where you can connect the scheme again. This method is often used to make textile push switches from three layers of cloth - 2 conductive coils, between which there is an insulation layer [65]. Examples (soft push switch) shown in 18.fig.

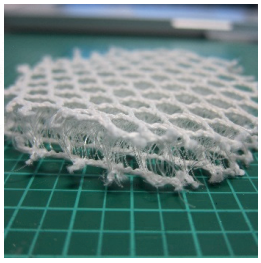
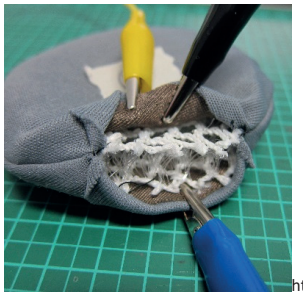


https://www.slideshare.net/marctena/abstract-of-mit-open-course-ware-new-textiles-10402068

http://www.kobakant.at/DIY/?p=5210



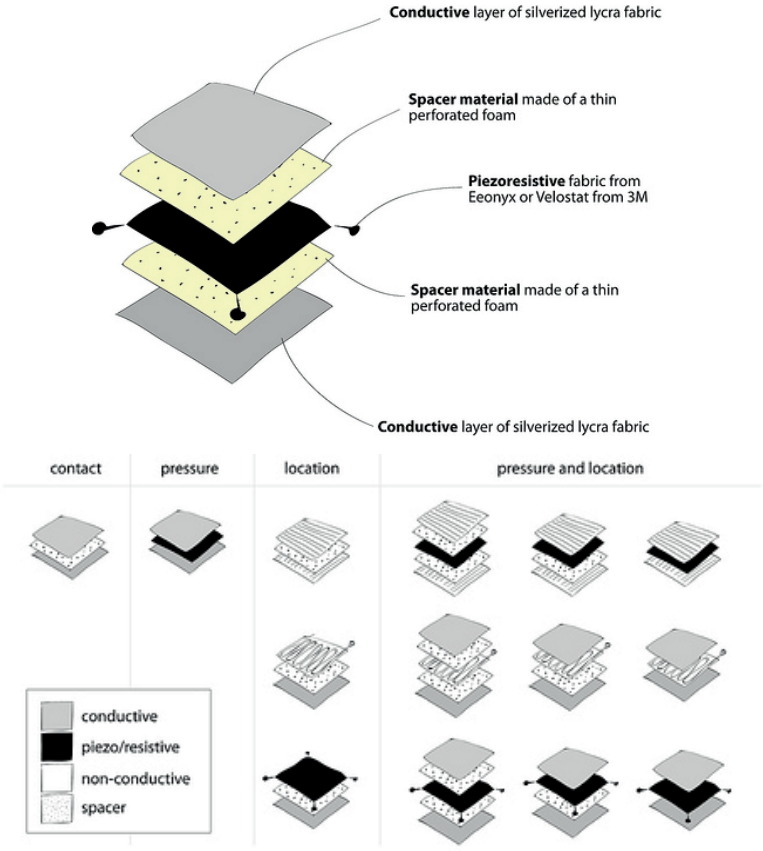



https://www.uni-weimar.de/projekte/costumes-and-sensors/simple-fabric-push-button/

18.fig. Soft push switch [66], [67][68]

Piezoelectric sensors based on the resistive principle consist of materials that change their electrical resistance in accordance with the applied pressure. The piezoelectric material can be between two layers of conductive material or it can form

an orthogonal conductor network. In the first case, the sensor can be made up of two layers of electrically conducting (or several separate conductive strips) layers between which a piezoresistance layer is arranged. In the latter case, you can use a piezoresistic cloth on which an orthogonal network is wound with a conducting yarn. One parallel group of lines is sliced on one side of the cloth, the other group of parallel lines on the side of the second cloth. The stitching of the sewing thread must be adjusted accordingly in order to keep the threads unrestrained [69].



19.fig. Piezoelectric sensors [70]

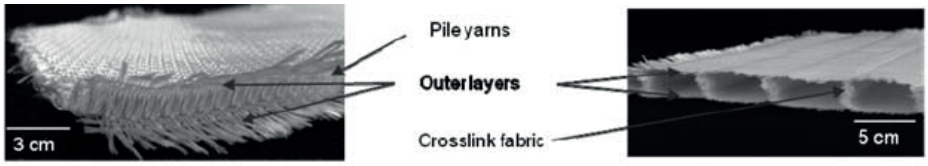
Such sensors can be used, for example, in wheelchairs (pressure distribution over the surface), compression socks (pressure monitoring), muscle activity measurements for leg and hand movement analysis, etc. The piezoelectric sensor principle can also be used for bending sensors. It operated on the basis of variations in pressure, which was applied as a result of bending of the sensor. By integrating the

sensor into clothing or an accessory, it is possible to measure the degree of bending of the body joints.

Capacitive sensors operate on the basis of a switchboard capacitor, which changes its resistance to the distance of the electrodes. The distance depends on the pressure caused by placing the compressible material between them. Application is similar to piezoelectric sensor. The principle is also used in the touch sensitive sensor / panel. It measures the capacity change when the finger touches the electrode. However, in this case, the sensor's lack of sensitivity is excessive, which may cause an activation of the error when it touches other objects. Nevertheless, the sensor is often used for smart clothes because of its simple fabrication and suitability for clothing [6].

Capacitive sensors can also be formed as individual electrodes matrices. One sensor layer consists of several separate electrodes, the second sensor layer - from a common electrode, creating a capacitor between each individual electrode and a common electrode. The individual electrodes matrix sensor is more flexible (at <100 electrode matrix) as a bar sensor, it is also more precise [71].

A multidimensional structure of the sensing sensor can be created using a three-dimensional weaving process. Using a traditional weaving technology with a modification of the beams (rebuilding), a capacitive textile sensor can be created. Sensor can be seen in 20.fig., it consists of two conductive layers, insulation and stabilization coils and intermediate ones [57].



20.fig.3D weaved sensor [57], [72]

1.2.3. Electric conductive connectors

Disconnected electrical connections can be used for various fittings that are commonly used for traditional clothing manufacturing. For example, metal pushbuttons, rivets, hooks, electro-coated padlock, etc. The electronics or electrical connection is soldered, glued, sewn or otherwise attached to the fittings and can act as a switch - open and close the electrical circuit.

A zipper can also be used for design of switches. Plastic zipper with metal cursor and metal fasteners will open and close the top of the zipper at the top when metal fasteners are connected or disconnected, i.e. when the zipper is opened or closed to the end. You can also create an analog or digital switch. Zipper switches are shown in 21.fig.

21.fig.Zipper switches [73], [74], [75]

In the case of an analog switch, moving the zipper cursor in the circuit increases or decreases the electrical resistance (more or less resistors are connected together). For example, the brightness of a light emitting diode gradually decreases or increases. In the case of a digital switch, each contact is fixed and the two terminals are connected, it operated as a separate switch. For example, if a particular diode is turned off.

One of the most commonly used techniques is push buttons that are seamlessly sewed with conductive yarn or put into the device with a push-button [76] [67]. 22.fig. a) figure shows push buttons that are seamed on a conductive cloth with conductive yarns and their connection closes the electrical circuit. Similar princip is 3.14. b) figure manufacturer *''Adafruit''* designes *FLORA* electronic module, which is fastened with push buttons.

a) b)

22.fig. Clamping of the electrically conductive chain with push buttons a) Pushbutton and conductive cloth b) ''Adafruit'' module

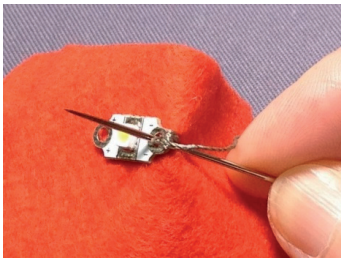
1.3. Preparation and connection of electronics elements to electrical insulation

In the process of designing intelligent textiles, it is important not only to understand the behavior of the conductive thread, but also the way in which the yarn pin connection is added to the system's electronic components. The mechanical connection quality is important when creating an electrical contact. Wires or steel threads can be soldered to the element - the contact will provide good electrical conductivity, but it can flutter due to bending. Electro conductive yarns are flexible and bending will result in less deformation, but problems are caused by their addition to electronics elements. Examples include manual assembly of a knot or a reverse shaft punch. When choosing an embroidery method, the sewing and strengthening of the lines at the electronics can be done in one continuous operation. In addition, an individual electrical circuit or various forms of connections can be programmed into a computer system and precisely embroidered with conductive yarns on fabric using a computer-guided embroidery machine. This is effective true if a complex electronic circuit is in place. In the research [77] there are two ways to add a thread to an individually designed plate - before hitting the hole in the element or creating holes in the sewing or embroidery process by piercing the element with a needle (using elements of a thin polymer material). Another type of thread attachment is the use of a conductive adhesive that simultaneously fixes the thread at the element and forms an electrical contact. The glue can also be used for additional reinforcement of the knot connection.

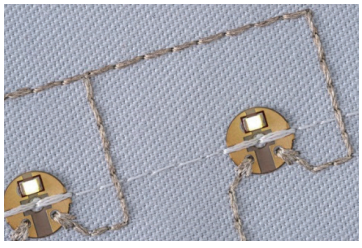
Another author [78] Electro-conductive textile design with embroidery technique is called e-stitching (*e-broidery*) or electronic embroidery. One of the ideas described by the authors is the use of different resistance threads in the textile scheme. This type of joint control allows replacing individual elements (such as capacitors, resistors, inductors) with a combination of resistance strings.

The connection type depends on the connecting elements, material, physical properties and other characteristics. Typically, sewing, gluing (with a conductive adhesive), soldering, or a combined method is used. If the textile circuit consists of soldered interconnections, the electronics element can be soldered directly to the circuit. But this is not always the case. As an example, light emitting diodes and their types are included, but this approach can also be used for other electronics elements.

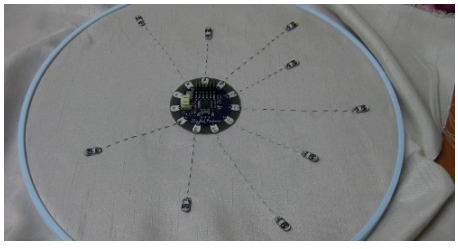
Light-emitting diodes are available in various sizes and corpuses. Commonly used diodes in a cylindrical corpus (T1) with a diameter of 3, 4 or 5 mm - using these diode types in e-textiles in design work, diode contact lenses are rolled up in a loop, behind which they are sewn to the textile with an electric conductor thread. Diodes are easy to sew, but due to their fairly high corpus, they form an uneven surface on the textile. Diodes are also available in a flattened corpus, such as square diodes with four contact leads. Together, the illuminated contact hinges make up the loops behind which the diodes can be sewn to the textile. Substrate soldered diodes (SMD LEDs) are smaller, for example, the 0402 diode parameters are 1 x 0.5 x 0.5 mm. In this case, there is a problem connecting the element and the textile material, since the diodes have no contact. To attach a diode to a textile material, metal fittings that are traditionally used for embroidering or making jewelry can be soldered to the contact areas of the diode.



https://www.kitronik.co.uk/blog/getting-started-e-textiles-basic-circuit-pcb-led/



http://www.technical-textiles.net/terms/events-techtextil-15

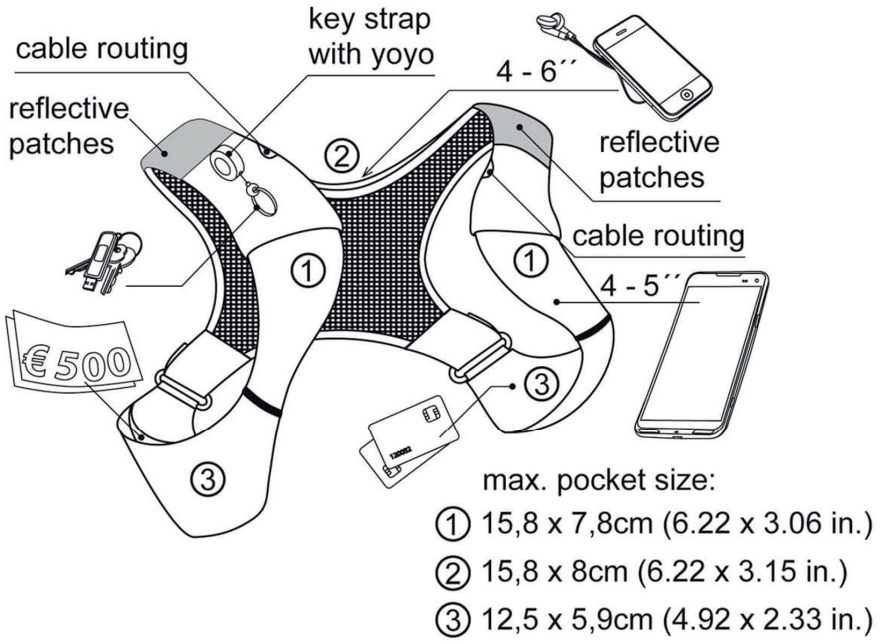


https://www.sparkfun.com/tutorials/312

23.fig. Diodes prepared for connection [79], [80], [81], [82], [83], [84], [85]

1.4. Development of close-fitting holsters (Lithuanian partner research)

The wireless data transmission function for protective outfits is particularly important because it is important to observe and watch over the tensions in the specific staff and, if necessary, provide assistance. Sensors should provide information on the key features of life and environmental pollution that may endanger human health or life. [86]. When wearing a vest with sensors that are in contact with the body, the data is sent online to the computer. The clothing is integrated with the Global Positioning System (GPS), which determines the location [87]. In some parts of the British police, police forces use head-mounted observation cameras and transmission systems to monitor and record tense situations. [88],[89].

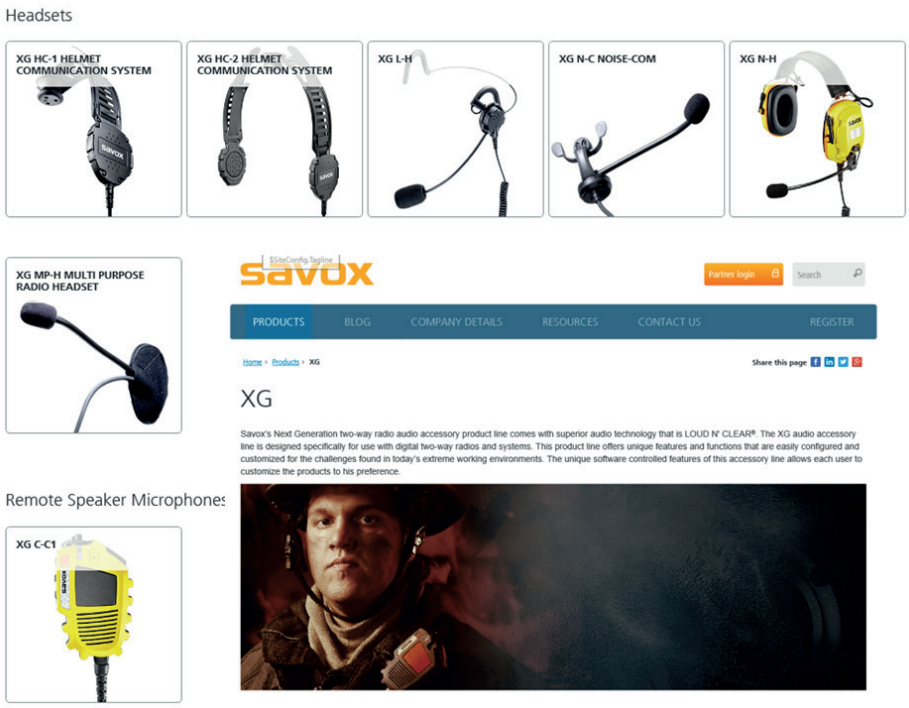


Close-fitting holsters that would integrate radio transmitters, headsets, remote speaker microphones and everything what is necessary for firefighters and rescue team members (devices are presented below) to ensure better communication between them during different type of accidents. The idea came analysing the products of URBAN TOOLS company (https://www.urbantool.com/en/), especially the one that is shown in the picture https://www.urbantool.com/en/product/running-vest/. Such vest would be universal. i.e. could be worn under the CPC (chemical protective clothing), which covers the whole body of firefighter together with gear (breathing apparatus, breathing

mask and helmet). Also it would be adjustable for lighter types of clothing, e.g. when gear is worn on the top of protective clothing.

Thus, we will use such technologies to incorporate electronic components into garment sewing and embroidering.

We have also searched the electronic communication solutions available in the market and we are planning to integrate the products of SAVOX company (https://www.savox.com/).



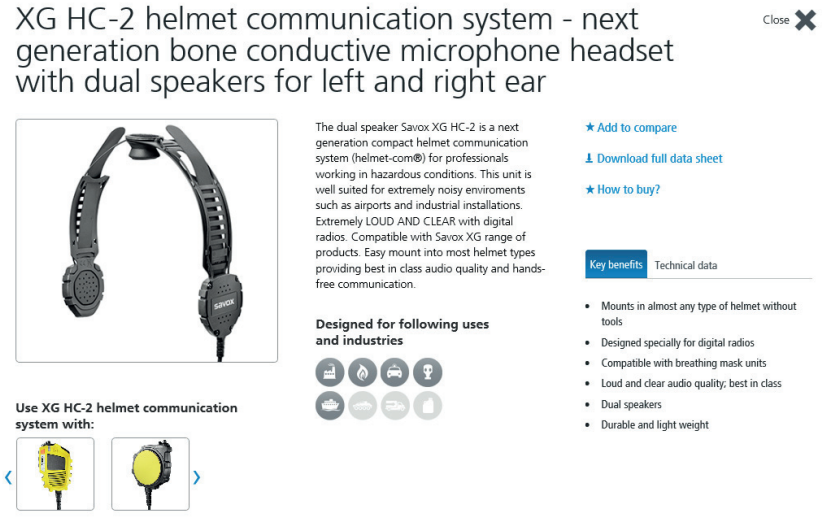
24.att.Savox headsets and remote speaker microphone

The description of XG product line: Savox's Next Generation two-way radio audio accessory product line comes with superior audio technology that is LOUD N' CLEAR®. The XG audio accessory line is designed specifically for use with digital two-way radios and systems. This product line offers unique features and functions that are easily configured and customized for the challenges found in today's extreme working environments. The unique software controlled features of this accessory line allows each user to customize the products to his preference.

An important part of such communication system is push-to-talk unit:

25.att.XG PTT-1push-to-talk unit

We are also planning to test the possibility to integrate headsets of new generation, which are bone conductive:

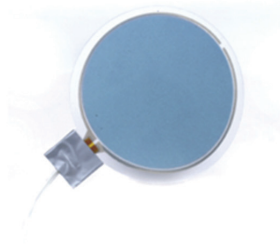


26.att.XG HC-1helmet system

We are planning to ensure the communication between firefighter team members not only by audio, but also by visual signals. For this purpose we are planning to use tape of ELLUMIGLOW company. (http://www.ellumiglow.com/).

VYNEL™ 1M STRIP LIGHT - VIBRANT BLUE

VYNEL™ BADGE PANEL LIGHT - VIBRANT BLUE



VYNEL™ SPHERE PANEL LIGHT - VIBRANT BLUE

27.att.tape of ELLUMIGLOW

2. SMART APPLICATIONS IN CHEMICAL INDUSTRY (Finland)

Survey performed by questioning workers from the chemical industry about their perception of various technological solutions incorporated into work wear can be summarized into those possible options to be implemented in work wear.

- Real time tracking of workers location to enhance security of the worker in dangerous situations
- Workers Attendance system
- Speech recognizing panel for sending message to a system and saving the message
- Gas sensors - alarm system for workers safety in work wear when there is any gas leakage or lack of oxygen.
- Timing system of different operations – monitoring workers starting and ending time when working with an individual machine.

Nowadays chemical industry needs smart system to manage environmental data, maintain the industrial workflow, assure safety of workers, etc. Adding different intelligent system can transform the chemical processing system through improvement of supply chain management and by increasing manufacturing operation process [90].It also has the ability to provide the technology, which has the ability to get the process data from different functional devices inside the industry. It needs connectivity for capturing data and different smart tools to do the conversion into an effective form [90]. Smart applications are involving in the industries maintenance in case of critical asset tracking tasks with the help of GPS, RFID and different smart sensors etc. It can help to ensure the product quality and integrity with entire supply chain management [91]. Passive and active RFID tags along with stretchable electronics technology can simplify the industrial process, data management, operational timing system by providing smart environment inside chemical industries [92]. Therefore, smart applications in chemical industrial environment can be useful in several aspects [92],

- asset maintenance
- responsive manufacturing
- supply chain management
- operational intelligence
- smart products and connected logistics

- security and data management
- dynamic procurement and smart contracts
- safety of workers

This project focuses on connection between different assets, environment, people, and products. RFID and stretchable electronics are the main technologies will be used to enable real time tracking and sensing in the working environment. The main objective and challenge is to incorporate these technologies into worker's cloth. Therefore technology components chosen have to survive up to several washing cycles, wearing, some stretching and bending, etc. Taking special care is necessary to ensure the chemical resistivity of those components so that it does not hamper the functions when it comes to chemical attachments. Those technological solutions will be useful to make it easier for both the worker and superiors to make immediate connection to each other inside the environment through the wireless communication system.

2.1. Tracking workers location inside industrial environment

RTLS (Real-Time Location System) is a wireless monitoring system, which consists of radio frequency identification technology. It reports real-time locations of tracked resources. RTLS is an indoor positioning system that uses WIFI to locate the exact position inside any industrial environment. It is easily configurable and maintained using mesh networking technology.

Radio Frequency Identification (RFID) is an automatic identification method, with both reading and writing ability to provide data in a particular device using RFID tags. RFID is a system to identify person, product or animals using radio waves [93]. It consists of silicone chip with RFID antennas. The passive tags need no internal power source while the active tags require some power source to provide energy continuously. RFID tags are the most important part of the indoor positioning inside the industrial environment. Because of the GPS location system is unable to deliver the operation inside industrial environment. It is valid only for outside areas [93]. Here are the benefits and application areas of real time tracking system,

Benefits [92]:

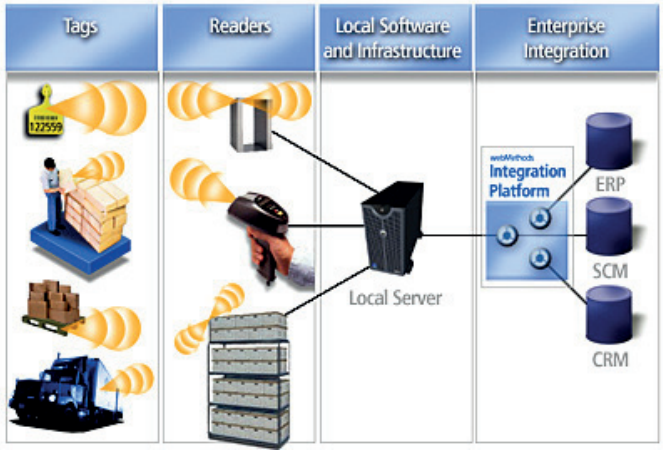
- Provides information about location using a web browser.
- Tracks the location of assets in real-time.
- Automatic alert system of asset events.

- History of asset position and movement recording for future purpose.
- RTLS uses minimal configuration.

Application areas [92]:

- Containers, Chassis in Shipyards
- Equipment, people in Healthcare/Enterprise
- Pallets/Cases, forklifts in Warehouses
- Cargo at Airports
- Cars in Manufacturing Plants, Parking Lots
- Books in the library

Figure 28 shows the process flow and technological set up for Real time locations system.

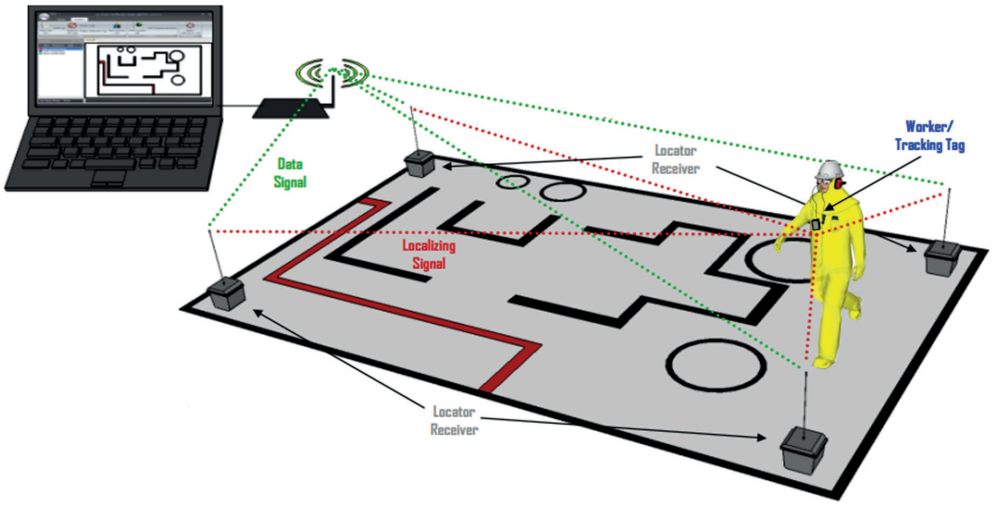


28.fig. Process flow and technological set up for Real time locations system[94]

2.1.1. RFID technology in smart work wear

So far, in this report, general ideas about RFID technology for real time location tracking. However, the main challenge is to do it on fabric, which can provide immediate response in some particular operation. The targets of using RFID tags are to provide workers identification in entrance, real time location tracking. It is also a useful part in workers operation timing system for particular task. In this project, an ultra-high frequency RFID tag has chosen for work textile. The frequency range is 860 MHz - 960 MHz The reading range of the antenna is 2-8 meters. More details on materials and fabrication process for this set up in work wear are in the later part of this report. Below,

shows the possible scenario of the technological set up for real time location system in work wear.



29.fig. Technological set up for real time location system in smart and safe work wear [95]

This real location tracking system has 4-locator receiver in the corners of the any particular part of the working environment. It has the ability to show the position of a worker through RFID tags attached to workers cloth. Signal transmits to those receivers remotely. Then, local software and infrastructure processes those signal via wireless signal transmission system. Different applications can also be significant in data controlling and signal modifying. Using the same tags, workers get connectivity to superiors and receive instructions for different steps. There are similar kind of technology has already been used in Borda technology. It is a product and solution development and system integration company, which mainly works on real time location tracking system and inventory management system. This company works with different RFID technology in research and development field.

Video link: https://www.youtube.com/watch?v=TtjSvikvfCk

GAO UHF 860 - 960 MHz Textile Cloth RFID Tag:

This RFID tag is useful for textile and it has the high mechanical stability during printing, dyeing and washing. The ideal uses are in laundry applications, supply chain management, asset tracking, process control and inventory control etc. These tags fulfill extreme demands need in smart work wear system. There are few other similar type of

tags are available in the same company. Table below shows the physical and functional parameters of the tags.

2.Table physical and functional parameters of GAO UHF 860 - 960 MHz Textile Cloth RFID Tag [96]

Physical Parameters	**Characterization**
Inlay dimension	125 mm x 7 mm
Package material	coated paper
Operating temperature	-40 °C to 65 °C
Storage temperature	-40 °C to 85 °C
Functional Parameters	**Characterization**
RFID IC QR2213	
RF frequency	860 to 960 MHz
Read distance	5 to 7 m

Textile cloth RFID tag: http://gaorfid.com/product/tag-print-dye-wash-resist-textile-cloth-uhf-860-960mhz-rfid/

GAO UHF 860 - 960 MHz Thin PVC RFID Card:

The materials used in this passive Gen 2 contactless PVC tag are PET materials. These materials allow the tag to withstand rough treatment. The frequency range is from 860MHz to 960MHz. It is flexible and read/write range from 2m for write to 1.5m for read depending on the reader. It is compliant with Phillip Ucode Gen 2 or Impinj Monza 96. This PVC tag is waterproof and dustproof and is resistant to different materials like salt water, alcohol, oil, 10% HCL and ammonia [97]. Table below shows the mechanical and technical description of GAO UHF 860 - 960 MHz Thin PVC RFID [97].

3.Table; Physical and functional parameters of GAO UHF 860 - 960 MHz Thin PVC RFID Card [97].

Physical Parameters	**Characterization**
Type	Contactless Read/Write
Operating Frequency	860 to 960 MHz
Integrated Circuit(IC)	Phillip UCode 1.19
Capacity	96 bit EPC ID
Data Coding Type	EPC Class 1 GEN2

Physical Parameters	Characterization
Common Usage	Any application where small form factor with longer range read capability is required
Tested Read Range	Maximum 2M write, 3.5 M read.Distance varying upon Readers
Multi-Detection	Yes
Tag Size	84(L)*54(W)*0.8(H) mm
Substrate Material	PET
Color	White
Weight	3 g
Compliance	Phillip Ucode Gen 2, Impinj Monza 96 etc

UHF thin PVC card: http://gaorfid.com/product/card-thin-pvc-passive-uhf-860-960mhz-rfid/

CAEN RFID tags

The design and materials of CAEN RFID tags has the specifications to use in places where there is need of waterproof tags. Also for robustness and ease of attachment this kind of tags are very useful.These are completely customizable tags, which means the color, shape, dimension, and materials are variable according to customers need [98].

The main descriptions are:

- Special tags for laundry with customizable shape
- Materials: silicone, rubber PVC or polypropylene
- Form factors: flexible or rigid, any shape and size, holes for hanging and sewing on fabric
- Applications tested: identification of textile and garment for hotels, hospitals and nursing homes

CAEN waterproof tags:
http://www.caenrfid.it/en/CaenProd.jsp?mypage=3&parent=120&idmod=809

Fujitsu RFID Tag:

Fujitsu RFID Tag WT-A511/A611 is an enhanced UHF washable tag featuring downsized dimensions and heat-sealing capability. It reduces cost-reduction for installation and operation [99]. These are very suitable for textile operation. It is possible to attach with textile in different methods including, sewing, embroidering, laminating etc. Once tags come in attachment to the reader, then it is helpful to use it as tracking system and security purpose.

4.Table: Physical and functional parameters of WT-A511/A611 [99]

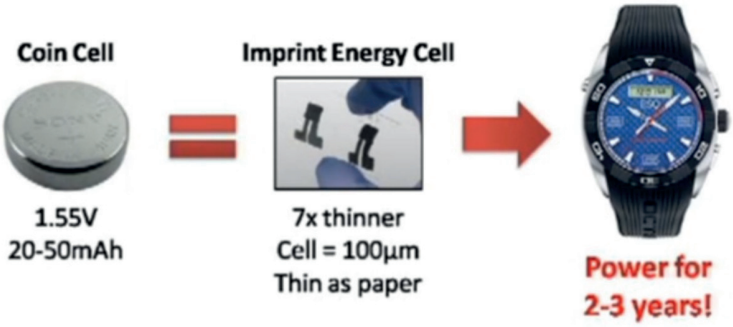
Item			**Specification**	
Model			Fujitsu RFID Tag WT-A511	Fujitsu RFID Tag WT-A611
Standard	RFID Standard		ISO/IEC 18000-6 TypeC (EPC Gen2)	
	Japanese Industrial Standard		Conforms to JIS L 0217 102, 103, 301, 401, 402 and JIS L 0856 Severe test	
Size & Weight			55(W)x10(D)x1.6(H)mm, 1g	
EPC Number Area			96bit (Note1-1)	96bit (Note1-2)
Reading Range	Textile	902 - 928MHz	4W eirp: 190 cm (Typical) 2W erp: 171 cm (Typical)	
		865.6 - 867.7MHz	2W erp: 130 cm (Typical)	
	Mat	902 - 928MHz	4W eirp: 200 cm (Typical)	
		865.6 - 867.7MHz	2W erp: 220 cm (Typical)	
Tagging			Sewing, Heat-sealing	
Lifetime			200 washing cycles or 3 years from shipping date, whichever comes first	
Environmental Resistance	Washing Method		Laundry, Dry cleaning (Perchloroethylene, Hydrocarbon solvent)	
	Sterilization Method		Autoclave sterilization	
	Water Resistance		Water resistant	

Item			Specification
	Chemical Resistance		Detergent, Softener, Bleach (Oxygen/ Chlorine), Alkali
	Heat Resistance	Drying	85ºC (Up to 60 min.) or 120ºC (Up to 10 min.)
		Ironing	200ºC (Up to 10 sec. with press cloth)
	Humidity/ Temperature	Operating	-20 to 50ºC, 10 to 95%RH
		Storage	-40 to 55ºC, 8 to 95%RH

WT-A511/A611 highly durable and flexible RFID tag - http://www.fujitsu.com

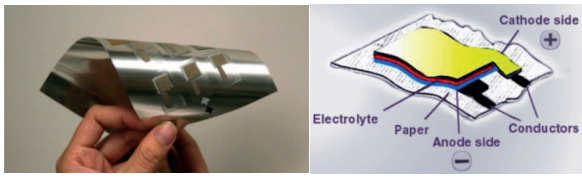
2.1.2. Flexible batteries

One key issue for using RFID as a wearable is the power source, battery. In the future more and more sensors are connected to RFID chips, meaning that more and more power is needed. Power source or battery must full-fill the requirements of using with wearables: flexible, thin, light and cheap. If it is permanently attached to the work wear it also has to be washable and in some extent stretchable. Therefore new kinds of batteries are needed. Printable and soft batteries are needed for wearable applications.



30.fig. **Coin cells may be sufficient for watches but not for wearables**

2.1.2.1. Imprint Energy printable batteries:



31.fig. Printable battery and its structure

The company Imprint Energy has developed a polymer electrolyte, which allows zinc based batteries to recharge. It does not allow formation of fingers and prevents bridging between liquid electrolytes and disables charging. The zinc anode is customizable and flexible as well as metal oxide cathode of the battery. It is printed in shape of electrochemical inks.

The process of printing is similar to silk screening as the material is deposited in a design after pushing it into a mesh over a template.

http://www.imprintenergy.com/

2.1.2.2. Enfucell soft battery:

Enfucell has developed an all-printed power source, which is flexible and thin primary battery made of low cost industrial eco-friendly materials. The battery consists of zinc and manganese dioxide, and zinc chloride as an electrolyte [100]. It is very efficient for devices like wireless sensors for healthcare, sports and logistics. Batteries are customizable according to need of application and effective to integrated devices, which they are powering. The technology enables different sizes from 1 cm^2 to 100 cm^2 and various shapes. Enfucell offers application-engineering services to help companies to develop innovative products that benefit from printed batteries. Enfucell batteries are flexible and have good performance on textile after providing the waterproofing sealant on it [100].

Video link: https://www.youtube.com/watch?v=n3N0asf0jKk

Enfucell powers: https://www.enfucell.com/

2.1.2.3. Blue Spark batteries:

Blue Spark Technologies has original patented thin printed battery design – is built on 1.5V carbon-zinc battery chemistry and provides high energy density. Voltages above 1.5V can be supplied by integrating multiple cells in series, into a single package. Batteries are typically capable of delivering peak drain currents of at least 1 mA. The batteries offer a significantly thinner profile than existing button or coin batteries and are eco-friendly. No heavy metal components, such as mercury, lead or cadmium.

Because they contain no harmful substances, the batteries are completely and safely disposable. Batteries are not designed for recharging.

The Blue Spark ST Series is well suited to a multitude of products and applications:

- Battery-assisted RFID
- RF-enabled sensor systems and data loggers
- RFID smart cards and ID badges
- Medical care devices
- Cosmetic patches
- Powered display customer loyalty and gift cards
- Interactive consumer goods packaging
- Merchandising displays

  http://www.bluesparktechnologies.com/

2.1.2.4. BrightVolt lithium polymer batteries:

Thin film batteries have revolutionized the battery industry. Birghtvolt batteries are thin film batteries with temperature resistibility. It can survive heat lamination up to 140C at 220 PSI [101]. Therefore, it has high stability in rough environment. It can be very good as power source for this project. These types of batteries are ultra-thin, flexible, environmentally safe, high energy density lithium polymer batteries. These are also customizable in several aspects [101].

BrightVolt lithium polymer batteries - http://www.brightvolt.com/products/flexion-batteries/

Product Features [101]:

- Safe and environmentally friendly
- Shelf life 2-5+ years depending on product chosen.
- Flexible: IS0 7816 Certified
- UL listed: UL1642
- UN 1-8 test certified
- Capacity: 10mAh to 48mAh
- Survives hot lamination (135°C) at 220 PSI
- Wide temperature range: -10° C to 60° C
- Ultra-thin: 0.37mm – 0.45mm
- Nominal voltage: 3.0 Volts
- High energy density
- Custom form factors

2.1.2.5. Other flexible thin battery manufacturers:

FlexEl's flat battery - http://www.flexelbattery.com/solutions/flexible-battery

THINERGY® Micro-Energy Cells (MECs) from infinite power solutions – http://www.cytech.com/products-ips

PowerStream Ultrathin Lithium Polymer Cells - http://www.powerstream.com/thin-lithium-ion.htm

Padre Electronics co., limited: http://www.pdbattery.com/ultra-thin-battery.html

2.2. Speech recording and sending system

For communication purpose, speech recognition panel plays an important part in this project. Speech recognition system has the ability to convert spoken language to machine-readable format. It only identifies speech when the words are very clearly. To ensure the received signal there will be some LED in work wear to give confirmation of received speech by the other device. Some sophisticated software helps in programming the speech-recognizing panel. The main operation of this panel is in the workers timing system. It helps workers by sending messages to superiors and by

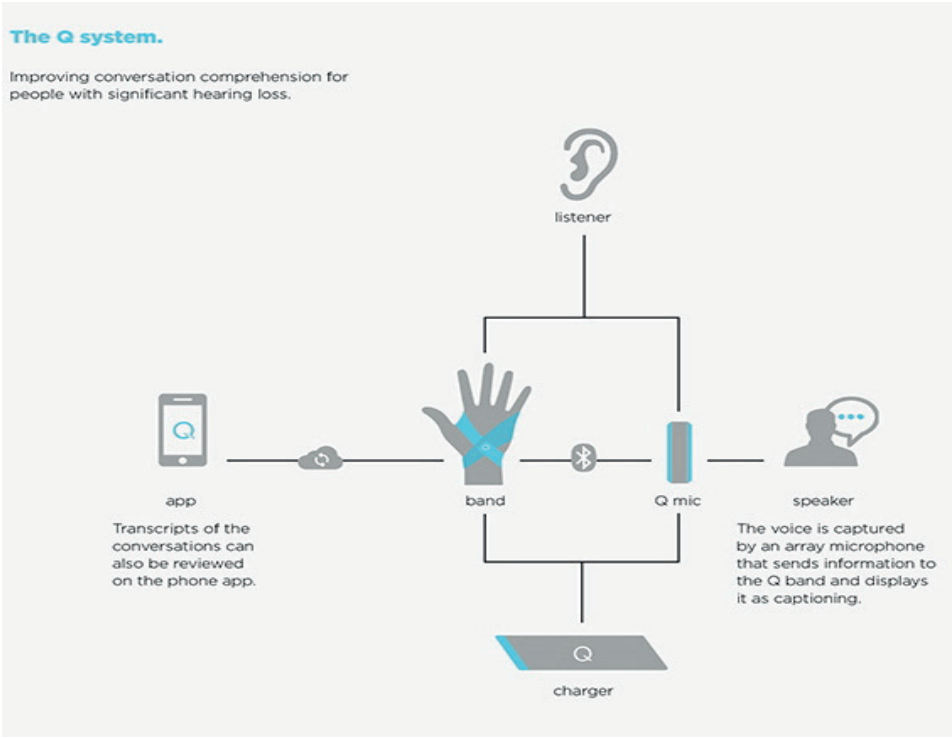
bookmarking through speech, which later on saves as text for future. To integrate this system on textile it needs microphone, transceiver (for transmitting and receiving signal) and other electronic circuitry. However, it is very hard to make this washable. Therefore, for this part it has planned to make it removable so that functions of this part does not get hamper when it comes in touch of water. There are some very good examples of speech recognizing technology has given below.

2.2.1. The Q system

http://www.core77.com/projects/55969/A-Wearable-Captioning-Device-for-the-Hearing-Impaired

The Q system is a wearable captioning device that displays text and graphed emotions to make understandable to people with hearing loss. This is very similar to the speech recognizing system for smart work wear. The system consists of a band on users hand [102].It looks like a watch. The band has display where the graphed emotions or text appears clearly. There is an array microphone attached to user's cloth, charging unit and some applications that help to make connection to smart phones or tablets. When a person is wearing the Q system, their voice is transmitted and to the band via Bluetooth technology [102]. Then, voice converts to text message using speech-recognizing software. Those texts appear in the OLED screen attached to cloth. The other features of this device are, (1) Transcript Recording, (2) Emoticaptioning, (3) Touch Speech, (4) Bookmarking. Transcripts, bookmarks, and a calendar is also accessible through the accompanying app [102].

Figure below shows the technological setup of the Q system [102].



32.fig. The technological setup of the Q system

2.2.2. IBM Watson speech to text

IBM Watson converts audio voice into written text. It helps to understand the content of multiple speakers, identifying the discussed topic, escalating calls etc. It uses speech to text to build different voice controlled applications. It is also possible to customize the model to improve language accuracy and different contents including product names, sensitive subjects, or names of individuals. The video below shows how it works.

Video link: https://www.youtube.com/watch?v=_Xcmh1LQB9I

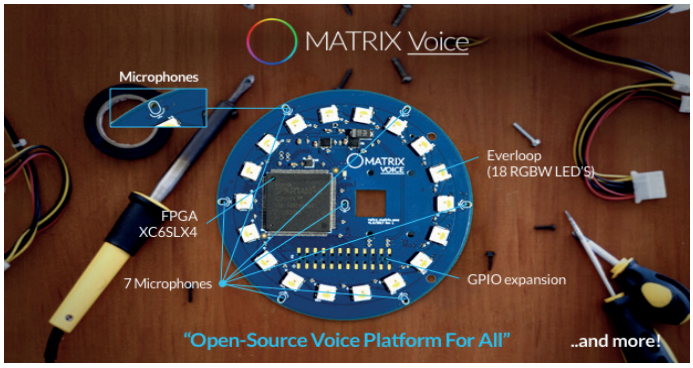
2.2.3. Senstone

This is a very small device, which is wearable on cloth, and it converts speech to notes. It is very easily moveable and useful to capture speech in any situation using just a click to the button. It converts ideas into notes using wireless communication technology. The video below shows how it works.

Video link: https://www.youtube.com/watch?v=fyLhQuSs6ts

2.2.4. MATRIX Voice

MATRIX Voice is an open-source VOICE RECOGNITION platform. It consists of 3.14-inches in diameter dev board, with a radial array of seven MEMS microphones, which makes connection to a Xilinx Spartan6 FPGA & 64 Mbit SDRAM with 18 RGBW LED's & 64 GPIO pins [14]. It has planned to make as removable device on work wear. It is also possible to sew the board on fabric or attaching with a zipper also effective. It provides developers the opportunity to do the integration of custom voice & silicone based hardware-accelerated machine learning technology. There is also an ESP32 Wi-Fi / BT enabled 32 bit microcontroller version is available in it. It is for makers, industrial and home IoT (internet of things) engineers [103]. It has FPGA-driven development board for the Raspberry Pi. It also includes, MATRIX Voice includes MATRIX OS, for simplification of hardware application development, which allows developers to build hardware applications very easily using JavaScript [103].

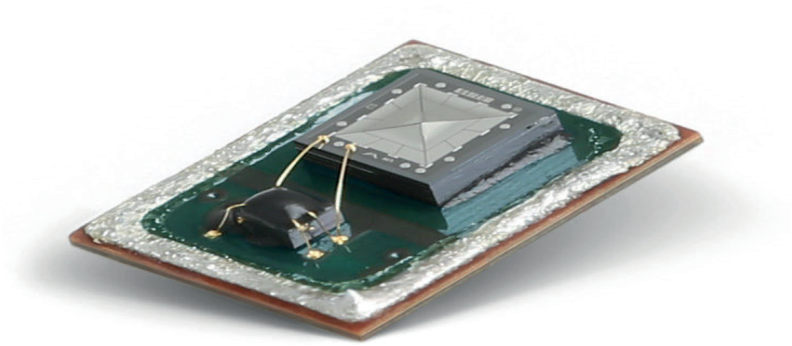


33.fig. Matrix voice recognition board [103]

2.2.5. MEMS microphone (VM 1000)

A piezoelectric MEMS microphone, VM1000 is the most robust and reliable MEMS microphone for consumer products. It is very good for wearable devices, smartphones and wearables to smart home devices, consumers use sound-enabled products. It is waterproof, dustproof, particle-resistant and shockproof device [104]. So, it can be very much immersed in water, bathed it in dust and can be expose it to particulate matter. It keeps working properly in rough conditions. It can be a very good option for integration on smart work wear as speech recognizing and recording system by adding other suitable electronic components (wireless communication system

circuitry) with it. VM1000 is very small in size (3.76 mm X 2.95 mm X 1.1 mm package). It has very high and low temperature stability (-40°C to +150°C). Figure below shows piezoelectric MEMS microphone VM1000 [104].



34.fig. Piezoelectric MEMS microphone VM1000 [104]

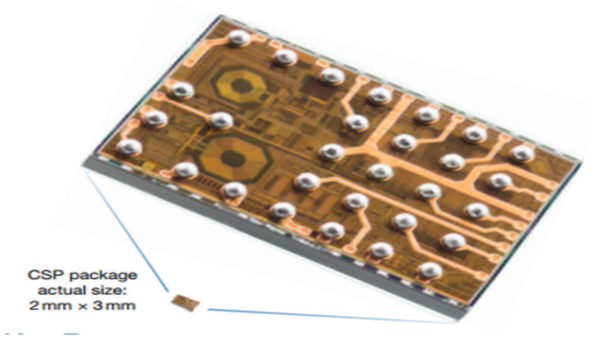
2.2.6. Microsemi's ZL70550 RF transceiver:

For integrating speech-recognizing panel, transceiver is very important part for transmitting and receiving speech signal from the user. For textile integration, Microsemi's ZL70550 RF transceiver is the lowest-power sub-GHz radio for high- or low-duty-cycle, wireless-sensor applications [105]. The device has very low power consumption in both active and sleep modes. It is the main feature of this device. A coin cell battery or an energy harvesting power source can power it. The ZL70550 device is also highly integrated and requires, in addition to the antenna, only a crystal, two decoupling capacitors, and a resistor. Available as a 2-mm-by-3-mm CSP, the device enables applications with very small places. Because of its size and very low power consumption, it can be very efficient for wearable applications. Figure shows Microsemi's ZL70550 Ultra-Low-Power Sub-GHz RF Transceiver [105].

Key Features [105]:

- Ultralow current of 2.4 mA in receive and 2.75 mA in transmit
- Ultralow sleep current of 10 nA
- CSP package actual size: 2mm × 3mm
- Maximum TX output power of 0 dBm
- Maximum RX sensitivity of −106 dBm
- Wide supply range of 1.71 V to 3.6 V
- Operates between 779 MHz and 965 MHz

- Industrial temperature range (−40°C to 85°C)

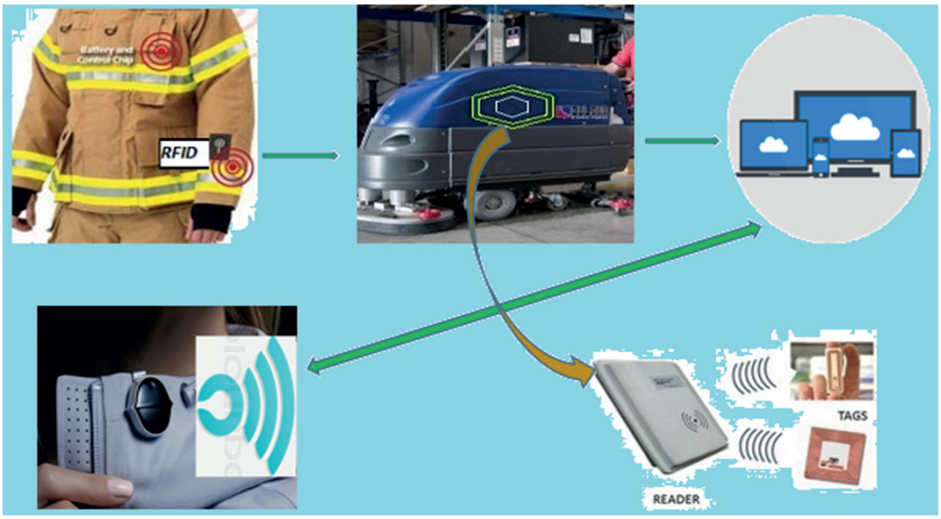


35.fig. Microsemi's ZL70550 Ultra-Low-Power Sub-GHz RF Transceiver [105]

2.3. Workers operational timing system

Figure below shows the process flow and technological requirements for workers operational timing system for some particular process where some worker will work with an individual equipment. This timing system will represent starting and finishing time for any task belongs to different staffs. It will ease the workers management system in industrial environment. It is an automatic process and the main target is to let other next worker about the starting and finishing time of any working machine who will use the same machine later on. This is one of the most important parts of this project. This technology consists of several parts:

- Flexible RFID tag on work wear with writing ability
- A mini Reader attached on machine
- Some applications for communication
- Speech recognizing panel with transceiver
- LEDS on work wear



36.fig. Process flow and technological requirements for workers operational timing system

The idea of this process is to identify workers identity first using stretchable and washable RFID tag on work wear. For easing the process, it is good to put it on wrist. There is a mini reader attached to the machine to read the tag and provide individual identity. Through wireless communication technology, the data transmits to superior or other workers who are going to work next with the same machine. Speech recognizing panel on the upper part of the cloth will help to communicate using speech. This panel is useful to send message to other staffs or to save important notes for future purpose. As the speech, recognizing panel only receives clear voice it has planned to put LED on work wear to get confirmation about received message. Therefore, the LED will change color whenever the system receives information. For this purpose, there is need of transceiver for not only transmitting but also receiving any signal. RFID tag on work cloth also has the writing ability. In this type of tags, there is very small memory space for storing some information. Saving some signal into tag in a digital format regarding the worker and work process is also possible in the memory. Therefore, whenever the tag comes in connection with reader it provides data about the worker and working process. This is also a very good way to provide operational timing of any particular task. In the next part, of the report there are some important information and links about the materials for this process.

2.3.1. Wireless RFID readers

Bluetooth UHF RFID Reader - DL930B [106]:

Daily RFID Co., limited:http://www.rfid-in-china.com/bluetooth-uhf-rfid-reader---dl930b.html

5.Table physical and functional parameters of Bluetooth UHF RFID Reader - DL930B [106]

Important performance	
Support protocol	ISO18000-6C EPC Gen2 / ISO18000-6B
Working frequency	ISM 902MHz ~ 928MHz, Or 920MHz ~ 925MHz
Customization	860MHz ~ 960MHz
Working mode	FHSS or working mode of fixed frequency pulse transmitting set by software
Transmit power	20 dBm ~ 30 dBm (set by software)
Read-Write performance	
Read speed	The average read time for single card is less than 10ms per 64 bits
Read distance	4m ~ 8m (tag and environment dependent)
Write speed	8bits less than 30ms
Write distance	2m ~ 4m (tag and environment dependent)
Read prompt	Buzzer

CAENRFID qIDmini (Model R1170I) bluetooth RFID reader

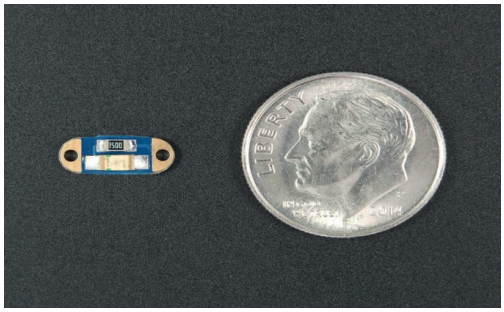
http://www.caenrfid.it/en/CaenProd.jsp?idmod=824&parent=61

Features [107]:

- EPC C1 G2, ISO 18000-6C Compliant
- USB and Bluetooth communication
- SPP and HID Bluetooth profiles
- Integrated linear polarized antenna
- Small, lightweight and ergonomic form factor
- Battery powered
- LCD display
- Vibration feedback
- iPhone/iPad compatibility
- Also available with Near Field antenna, optimized for Murata MAGICSTRAP® and HITACHI USPT miniaturized tags.

2.3.2. Washable LED

TinyLily LED 1206:



https://tinycircuits.com/products/tinylily-led-1206

A compact sized of 10.2mm x 4mm LED, with two standards TinyLily sew tabs and a current limiting resistor [108].

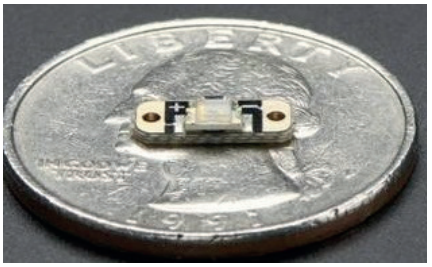
Technical details [108]:

- Washable
- Two Sew tabs – 1.2mm in diameter, easy to use with standard conductive thread and needles
- Robust Gold Finish – makes soldering easy and is non-corrosive

LilyPad LED White

https://www.sparkfun.com/products/13902

A simple pack of five White LilyPad LEDs attached to one another, it can be sewn into clothing. LilyPad is a wearable e-textile technology developed by Dr. Leah Buechley and cooperatively designed by Leah and SparkFun. It has large sew tabs to allow them to be sewn into fabric. They are also washable (with special care) [109].



Adafruit LED sequins

https://www.adafruit.com/product/1792

Adafruit LED Sequin is a Sewable little LED for wearable devices. It has a single color. However, LEDs fade and twinkle making is available by using the PWM (a.k.a. analog Write). The size (4mm x 9mm / .16" x .35", 2mm thick) of the LED makes easier to use it in projects [110].

2.4. Gas sensing system in work wear

Smart gas sensing system in work cloth plays a key role for this project. For attaching the gas sensing system in textile, it needs to make the whole integration system washable. Normally integration system for sensing system requires gas sensor, power source, wireless communication technology etc. After looking at the industrial

environment and projects requirements, it seems that oxygen sensor for monitoring oxygen concentration has the biggest priority. Therefore, the project is concentrating on oxygen sensing system for environment. The initial idea was to attach some washable gas sensor to work wear. As, it is hard to make it washable the idea is to make it removable. Sensors housing are inside a pocket or a removable zipper for removing the sensor and integrated circuit before washing the cloth. There is one very good Bluetooth low energy gas sensing system, which comes with a whole package. Texas instruments are the manufacturer of this product. The size is small and fulfills the requirements of this project.

TEXAS INSTRUMENTS Gas Sensor solution with Bluetooth Low Energy: http://www.ti.com/lit/ug/snoa922/snoa922.pdf

This gas sensor platform has Bluetooth low energy wireless network technology that customer can use for industrial applications. The function of this device is to monitor gases like carbon monoxide (CO), oxygen (O2), ammonia, fluorine, chlorine dioxide and others. The size and shape of this device is good for attaching on work cloths. It provides connectivity to smart phones and tabs. Users can replace the targeted gases automatically using applications. CR2032 coin-cell battery runs on the device as power source. The plan is to put whole system in a small pocket inside work wear. For making the device water resistant and harmful chemical resistant, some special protection membrane will be very effective. For this, special attention is required, so that gases pass through this membrane easily. Here are the main features of this device [111].

Features [111]:

- Three lead electrochemical gas sensing: CO, Ammonia, Fluorine etc.
- Two lead galvanic cell gas sensing: O2.
- Bluetooth Low Energy radio, 8051 micro controller core within CC2541 provides interactivity with a smartphone and tablet.
- Adjustable cell bias and TIA of LMP91000 along with low power and accuracy provide flexibility, performance and low power solution.
- Coin cell operation
- Ensures quick time to market for customers using firmware and application software provided as open source.

Figure below shows Gas Sensor Platform with Bluetooth Low Energy Evaluation Module.

37.fig. Texas Instruments gas Sensor Platform with bluetooth Low Energy Evaluation Module [111]

Small oxygen sensor SK-25F:

http://www.figarosensor.com/products/entry/sk-25f.html

As oxygen, sensing has the most priority in this project, more market research has done to search available oxygen gas sensor. So that it can be integrated together with some wireless network technology for building this oxygen gas sensing system. Figaro Oxygen Sensor, SK-25F, seems to be the more appropriate one. As it has the ability to fulfill attachment with textiles easily in terms of size, shape, weight and sensing principle [112]. The figure, Specifications and features is given below,

38.fig. SK-25F oxygen gas sensor [112]

6.Table; Physical and functional parameters of Small oxygen sensor SK-25F [112]

Target gases	Oxygen
Typical detection range	0-30% O2
Sensing principle	Galvanic cell

Operating conditions	-5˚C ~ 50˚C, 0 ~ 99R.H. (no condensation)
Dimensions	φ20.4×16.6mm
Weight	Approx. 7.0g

Features [112]:

- Virtually no influence from CO2, CO, H2S, NO, H2
- Temperature compensation circuit included
- Good linearity
- No position dependency
- Stable output signal
- No external power supply required for sensor operation
- No warmup time is required

2.5. Other methods

There is no doubt that, combining washable and wearable sensor on textile is a challenging task. It has seen from market research that attaching sensors on work wear will make the system very much complicated. Therefore, the alternate idea is to put gas sensors in different places of industrial environment. It is an easy solution for this task, as these sensors are very much available in the market. RFID and gas monitoring sensor together makes an efficient combination for observing uniquely identifiable sensor networks at short and long ranges. The sensing system has the ability to collect relevant data related to different gas sensors using battery powered active, RF energy harvested RFID or Passive RFID tags in work wear. The components for this system are:

- Wireless gas sensor in environment
- RFID reader
- Passive/ active RFID tags in work wear
- Alarm system

The use of RFID for automatic transmission of physical parameters shows a way to a large number of applications. In this technique, battery operated wireless gas sensor are connected to reader. The work consists of connecting the reader and wireless sensor network system and programming the wireless connection to RFID tag. After attaching tags on work wear, environmental gas sensor, transmits important signal,

connected to a reader. When a worker will work in the range of this tag, it will send the information about different gas concertation inside that working area. The aim of the project is to ensure workers safety during gas leakage or detecting gas concentration. This system has the ability to show real time gas monitoring of environment without any discontinuation. It will also include an alarm system. By this, the control system will send immediate response to worker through LED integrated on work wear.

3. SMART MILITARY EQUIPMENT (Latvia)

Smart materials, wearable technologies, smart clothing has become a significant part of the military uniforms all over the world. Governments and military organizations invest large amounts of money in research and development of new military uniforms in order to increase and improve soldiers' performance, empower human functions, to provide the health monitoring of each individual soldier as well as the environmental threats, to control and oversee the situation in the battlefield and gain the tactical advantage over the enemy. The smart textile and wearable technology market for military purposes are expected to grow tremendously in the next few years. Police, rescue and fire service, and ambulance in their work also started using smart textiles [22; 40].

The United States has developed a smart military uniform with a wearer's health monitoring function. The uniforms provide that an integrated sensor determine the location of the wound, the severity of the damage, and detects the presence of chemicals in the blood and sweat. Data from the sensor is processed and sent to the medical computer. When arriving at a wounded soldier, the medics have full information about his injuries, so he can immediately provide the necessary medical assistance. In turn, the commander sees the wounded and fallen, watching the digital battle charts, a place and number that help to choose the most appropriate strategies for future action [86].

Within the framework of the US-developed Future Force Warrior system, one of the data transmission features in the clothing is described. Clothing with a sensor monitoring system controls the temperature of the skin, the heart rate and the amount of fluid intake. In this way, the medical staffs are able to monitor, diagnose and alert the soldier at a distance, for example, for the sunscreen. To communicate with members, the communication system does not need to be turned on manually, but it can be done with the voice detected by the sensor [100].

Within the framework of the project, the needs of the end users were analyzed in order to create potential smart application solutions that would be useful and convenient for the improvement of Latvian military uniforms. The main needs and requirements for protective work wear highlighted by the end user were – increased flexibility and mobility, functionality, lightweight, moisture regulation, long lasting

protection against wind and rain, suitability for multi-climate conditions, protection against hazards in the battlefield, washable.

3.1. Research and development for military purposes

To create such potential solutions and propositions for development and improvement of the current uniforms the materials and technological solutions in the market as well as the scientific achievements in the filed were analyzed.

The main research and development areas are:

- protective clothing (protection against injuries and hazards in the battlefield)
- wound detection (with integrated sensors)
- health/stress monitoring (with integrated sensors)
- energy harvesting (in order to maintain the communication)
- creating the "future super soldier" (exosuits)

Research institutions are developing materials that could protect soldiers from battlefield injuries such as impact of bullets, explosive fragments, stabbing weapons as well as injuries caused by toxic, corrosive gases and liquid chemicals, biological, radioactive and electromagnetic exposure. By creating and integrating smart uniforms, the injuries obtained during the battle can be reduced, thus reducing the loss of soldiers and cost of treatment.

The materials that are used for protective clothing against biological and chemical damages react to the chemicals, thus detecting potential exposure risk. Textile materials that protects against intense heat and flames are widely used within the firefighting forces, such fibers do not melt and provide protection against heat and flames even after extended exposure.

For military forces it is crucial that the materials used for uniforms are lightweight and do not limit the flexibility and mobility of the soldier or interfere with its performance. Smart textiles should meet all the requirements of comfort (moisture regulation, breathability, and antistatic, suitable for multi-climate conditions), safety (protection against hazards and injuries as well as environmental conditions) and ergonomic requirements, uniforms made from smart materials should be washable and maintain long-lasting protection.

Researchers and industry leaders have developed garments – wearable technology – for military that collects physiological data to detect stress, health status,

wounds and injuries sustained during the battle. Sensors are flexible, washable (or easy removable before washing), integrated into the clothing making them as non-disturbing as possible (such sensors are coated or embedded in to the smart clothing). Using of nanotechnology has provided a drastic reduction in size of sensors as well. The collected data could be useful for further analysis of military combats in order to improve the planning of future activities and to minimize casualties.

Sensors that are used in smart clothing can be divided into three main categories – physiological, kinetic and agent detection sensors.

Physiological sensors measure respiration rate, heart rate, brain activity, blood pressure, blood oxygenation and body temperature, urine and saliva composition, sweat chemistry, sleep quality, position, activity, posture etc. – sensors that are used to detect injuries, stress and trauma.

Kinetic sensors measure steps, pressure, acceleration, direction and location, they are used to detect stress and injuries, as well as generate the electricity and control and plan the further movements and activities of the combat units.

Environmental agent detection sensors measure chemical, biological (viruses, bacteria, fungi) pollution, radiation, atmospheric pressure, humidity and temperature in order to identify the possible danger and to help to avoid them.

To provide the necessary energy to maintain the communication and the functioning of the devices, the necessity to generate and collect energy becomes more and more crucial. One of the first attempts to collect the energy was specialized blankets that contained solar cells used to generate electricity. Nowadays the energy harvesting systems are more developed – a new generation of sensors are used and integrated into the smart uniforms to transform kinetic energy into electricity. As for the connection of the electronic equipment to the power source, to avoid cables that are heavy and inconvenient to carry, besides they lack flexibility, conductive materials are used in the garments to transmit electricity from the energy source to the device, making the uniform less heavy and increasing the overall flexibility.

To empower human functions and ease the physical burden of the soldier, research institutions are working to create exosceletons – exosuits that mimics the action of leg muscles when walking.

The leading companies providing smart clothing, textiles, wearable technology for military forces worldwide are:

- BAE Systems
- Midé Technology
- Ohmatext
- TenCate
- W.L Gore & Associates
- Advanced Fabric Technologies
- BeBop Sensors
- Directa Plus
- DuPont
- Intelligent Textiles
- Outlast Technologies

3.2. Smart and safe military uniforms

Having determined the needs of the end-user and analyzed the issues the end-user meets while wearing the uniform, the concept of improvement and individualization of army field uniform (level four) was established including the following:

- Fabric choice improvement – smart textiles – selecting fabrics with increased elongation capacity (at least 40%) and flexibility to ensure freedom of movement and avoid premature bursting of the uniform fabric during rapid and broad movements. Elastic parts should be integrated in the single crotch wedge part to ensure personal comfort, freedom of movements and increase the longevity of uniform.
- In addition, the breathing and air permeability capacity of the fabric should be increased to provide the necessary microclimate, to ensure the individual comfort and improve the performance.
- To ensure better textile materials' supply, new NAF technical specification should be developed containing such additional characteristics as the warp and weft density, elongation at the breaking point, tearing strength, abrasion resistance, besides some of the requirements for textiles should be increased for example the minimum tensile strength in the transverse direction considering that while wearing the uniforms are exposed to heavy loads.

- Construction and technology improvement – the existing construction should be improved to avoid premature bursting and to ensure freedom of movements, adjusting the construction to the target populations' anthropometric characteristics and motion specifics.
- As for the technology improvements, having analyzed the strength of the field uniform seam connections (in the parts of the uniform that are exposed to heavy loads the most, such as the crotch part for example), it has been determined that for connecting the parts stronger type of connection must be used (4 stiches per centimeter for connection seam).
- Anthropometrics – creation of new generation workwear prototypes – to provide the comfort and freedom of movement for each individual wearer, it is crucially important to implement the body size correlations. Part of the target population was measured via the 3D scanning, gathering wide range of body measurements for designing and constructing protective clothing, as well as obtaining the necessary information for distributing the wearers per accurate body sizes. Analyzing the data obtained during 3D scanning of different body postures (specific for soldiers' daily work process), it is possible to create uniform prototypes that are more convenient for end-users' needs.

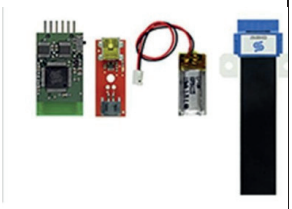
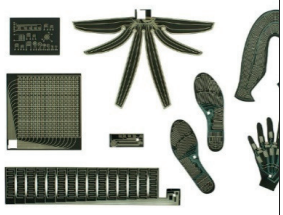
Furthermore, based on the gathered information, new apparel labeling system should be implemented so that the selection of uniforms of the appropriate size would be more accurate and simple.

- Identifying and maintenance of uniforms – RFID integration into workwear – to avoid the improper product care and its premature deterioration the centralized uniform maintenance system should be developed. To introduce such system, RFID tags (chips) would be recommended to be integrated into each item of the uniform, thereby providing the individualization of the uniform, centralized cleaning and accurate tracking system of the inventory units. RFID tags can be directly integrated in to the apparel and are washable.
- Light signal integration into the back side of the field uniform jacket – in order to provide the solders visibility and to alert the other group members about the possible threats in deteriorated visibility conditions.

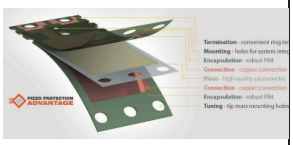
3.3. Examples of smart military equipment used by military forces worldwide

3.3.1. Fabric sensors for physiological data monitoring

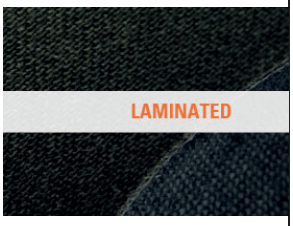
<table>
<tr>
<td>  </td>
<td>BioHarness
Developed for the military, first responders and human performance
BioHarness™ 3 couples the pioneering Smart Fabric sensor technology of the comfortable and unobtrusive BioHarness™ garment with the power and ubiquity of Bluetooth®. BioHarness™ 3 enables the capture and transmission of comprehensive physiological data on the wearer via mobile and fixed data networks – enabling genuine remote monitoring of human performance and condition in the real world.
http://www.zephyr-technology.nl/en/product/71/zephyr-bioharness.html</td>
</tr>
<tr>
<td> 
</td>
<td>Team Compression Shirt
Support the following measurements:
• Heart Rate
• Heart Rate Recovery
• Heart Rate Variability
• Accelerometry
• Intensity & Load
• GPS Sensors (GPS Receiver sold separately)
Features:
• Smooth fabric provides complete comfort without restriction
• Compression fit bolsters muscle support and increases circulation
• Moves moisture away from the body for ultimate comfort
• Machine Washable</td>
</tr>
</table>

	http://www.zephyr-technology.nl/en/product/73/team-compression-shirt.html
	**Hexoskin** Hexoskin offers the only clinically validated system that allows precise ECG cardiac monitoring with lung function and activity monitoring over the long-term. Products, software and data analytics provide the communication tools to help doctors, nurses, and caregivers improve the standards of care for outpatients. *http://www.hexoskin.com/pages/health-research*
	**Midé Technology** Stretchable, wearable sensor solutions (with electroactive polymers) - perfect for the unobtrusive measurement of human body motion in the animation, augmented reality, sport, healthcare, and prosthetic industries. *http://www.mide.com/collections/smart-materials/products/stretchsense-evaluation-kit*
	**Fabric Stretch Sensor Kit (Midé Technology)** A field-ready wearable motion sensor, designed to provide extremely precise realtime data on the motion of a soft object, like the human body. *http://www.mide.com/collections/smart-materials/products/fabric-stretch-sensor-kit*
	**Bebopsensors** Washable fabric can measure XYZ location, Bend, Twist, Rotation, and Force. Materials available in woven and non-woven base cloth Printed layers include dielectric, resistive and controlled conductive *http://www.bebopsensors.com/technology/*

3.3.2. Energy harvesting

	**Midé Technology** Piezoelectric products can be used for a wide range of applications, including energy harvesting, solid state cooling, haptic feedback, and general actuating and sensing. *http://www.mide.com/collections/piezoelectric-products*

3.3.3. Military uniforms using smart materials

	**TenCate Defender™ M** TenCate Defender™ M fabric has been supplied to millions of soldiers and police officers worldwide, protecting them in conflict zones – on land, in the air and at sea. This is a comprehensive range of fabrics that exceeds all others in terms of quality, comfort and FR performance. *http://www.tencate.com/emea/protective-fabrics/markets/military-and-police/products/inherent-fr-camouflage-and-light-uni-colours/default.aspx*
	**TenCate Defender™ M** *http://www.tencate.com/emea/protective-fabrics/markets/military-and-police/products/inherent-FR-Dark-uni-colours/default.aspx*
	**TenCate** Laminated FR fabrics for comfortable and waterproof operational uniforms. Provide protection against wind and rain, with excellent moisture regulation and breathable properties. *http://www.tencate.com/emea/protective-fabrics/markets/military-and-police/products/inherent-FR-Laminated/default.aspx*

	**W.L Gore & Associates** Flame-retardant and antistatic properties, the lightweight Fire-Resistant Environmental Ensemble (FREE) withstands heat and flame threats that soldiers may encounter in combat vehicle crew and aviation mission sets. FREE EWOL is designed with a Nomex® outer layer, a durably waterproof, windproof, and breathable GORE-TEX® membrane, and a Nomex® liner. Highly breathable GORE-TEX® fabric keeps the user comfortable by allowing moisture to escape from the garment. GORE-TEX® fabric maintains protection over time, even after exposure to JP-8, DEET, petroleum, oils, and lubricants. The n-IR signature reduction technology is durable for the life of the product. Only routine washing and drying is required to maintain the performance, and extends the life of the garment *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/Fire-Resistant-Environmental-Ensemble*
	**W.L Gore & Associates** Engineered for rain, high wind, and extreme cold conditions, the lightweight Gen III ECWCS Level 6 jacket and trouse deliver unsurpassed comfort in a broad range of weather conditions. These lightweight garments are extremely packable, which allows you to move around and react to changing field conditions more quickly. *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/ECWCS-3G-Level-6*

	**W.L Gore & Associates** Durable protection and comfort in hot weather, including being suitable for temperate, arid and tropical environments. This fabric offers the best combination of air permeability, fast dry time, strength to weight ratio, and no melt/no drip during flash-fire incidents. *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/GORE-Katana*
	**W.L Gore & Associates** Durable and highly breathable with enhanced flame protection *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/Massif-Battleshield-and-Battleshield-X*
	**W.L Gore & Associates** Hardshell with GORE® PYRAD® Flame Retardant Durable performance and comfort with enhanced flame protection *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/GORE-PYRAD-Hardshell*
	**W.L Gore & Associates** The lightweight Gen II ECWCS jacket and trouser is engineered for rain, high wind, and extreme cold conditions, delivering unsurpassed comfort in a broad range of weather conditions. *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/ECWCS-2G*

	**W.L Gore & Associates** Flame-Resistant Fuel-Handler Coverall Breathable comfort with excellent antistatic and burn protection *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/Flame-Resistant-Fuel-Handler-Coverall*
	**W.L Gore & Associates** Fuel-Protective Coverall Breathable comfort and protection against fuels and contaminants *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/Army-Fuel-Protective-Coverall*
	**W.L Gore & Associates** Lightweight, breathable comfort with protection against flash-fire *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Outerwear/FR-Low-Loft-Jacket*
	**W.L Gore & Associates** Durably water-resistant and lightweight cold weather clothing system *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Army-Next-Generation/Lightweight-Loft-Level-3B*
	**W.L Gore & Associates** Durable waterproof and breathable weather protection *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Special-Operations-Outerwear/PCU-Level-6*

	**W.L Gore & Associates** Lightweight systems for multi-climate conditions *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Special-Operations-Outerwear/ArcTeryx-LEAF*
	**W.L Gore & Associates** GORE-TEX® FR Linebacker Jacket with GORE® PYRAD® Flame Retardant Fire protection and breathable comfort in extreme weather *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Special-Operations-Outerwear/FR-Linebacker-Jacket-with-GORE-PYRAD-Flame-Retardant*
	**W.L Gore & Associates** Durably water-resistant and windproof parka *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Special-Operations-Outerwear/WP2-Rogue-Parka*
	**W.L Gore & Associates** Functionality mapped technical outerwear Performance Zone garments are designed with high-performance GORE-TEX® fabrics. Fabrics are strategically placed in different parts of the garment based on various functional and climatic zones of the body. The end result is the most comfortable, durably waterproof outerwear. *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Special-Operations-Capabilities/Performance-Zone*

	**W.L Gore & Associates** Equal performance in multi-climate conditions Durable waterproof, windproof, and breathable protection Increased flexibility with reversible camouflage fabric Long-lasting protection in multiple operational theatres Consolidation and simplification of cold weather clothing system with fewer garments and reduced inventory *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Special-Operations-Capabilities/Reversible-Outerwear*
	**W.L Gore & Associates** Highly Tactile Flame-Retardant Combat Glove Retains warmth in cool and wet conditions The construction delivers optimal tactility without compromising the ability to handle small objects, weapons and equipment. Engineered with flame-retardant materials, this glove provides protection against flash fires. *http://www.goreprotectivefabrics.com/remote/Satellite/Military-Special-Operations-Capabilities/Highly-Tactile-Flame-Retardant-Combat-Glove*
	**DuPont** Nomex® Fabric—Proven Protection for Military and Police Nomex® fabric helps provide uniforms with proven protection against intense heat and flames. When exposed to extreme heat, Nomex® undergoes a special reaction, changing its properties to capture more energy in the fabric, giving the wearer valuable extra seconds of protection from heat transfer.

	It features the lowest possible weight at the highest level of protection; breathability for reduced heat stress; the ability to effectively wick away moisture; and durability to perform in a wide range of conditions. *http://www.dupont.com/products-and-services/personal-protective-equipment/thermal-protective/brands/nomex-fabric.html*
	**DuPont** Vests - protection against threats like bullets, stabbing weapons, and fire. *http://www.dupont.com/industries/safety-protection/law-enforcement-protection.html*
	**DuPont** Kevlar® fiber for Military - KM2 Plus – the most protective DuPont fiber for the most hazardous duty. Highest grade protective fiber for military use offers increased process-ability for conversion to woven fabrics and structures for ballistic fabric weavers and body armor manufacturers. Military combat helmets and tactical vests made with Kevlar® KM2® Plus helps manufacturers provide superior resistance against bullets and fragments, while maintaining a lighter weight for increased comfort and mobility. *http://www.dupont.com/products-and-services/fabrics-fibers-nonwovens/fibers/brands/kevlar/products/kevlar-km2-plus.html*
	**DuPont** Army Aircraft Crew Uniform

	**DuPont** Flyers Coveralls
	**DuPont** Combat Vehicle Crewman Uniforms (CVCU) offer significantly more protection from fire hazards and burn injury than standard ACUs.
	**DuPont** Multi-Climate Protection System (MCPS). Designed to perform in the tough environments above the earth, MCPS offers six specially designed layers to give aircrewmen optimal thermal protection in all weather conditions.
	**DuPont** Flame-Resistant Army Combat Uniform (FRACU) offers superior Nomex® flame resistance and durability.
	**DuPont** Military helmets offer protection against a wide range of threats, including submachine-gun bullets and fragments, they are lightweight, it helps to improve mobility and reduce fatigue to give warfighters the much-needed energy to complete their mission. *http://www.dupont.com/products-and-services/personal-protective-equipment/body-armor/uses-and-applications/military-helmets.html*

3.3.4. Protection against chemicals

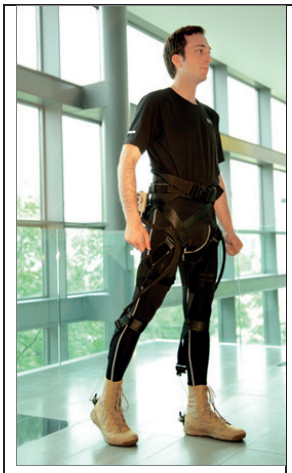
	**DuPont** High level of protection against toxic, corrosive gases and liquid chemicals. Provides at least 30 minutes of protection against over 320 chemical challenges *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-tk.html*
	**DuPont** Chemical protection available against hundreds of toxic liquids and vapors from sarin to chlorine gas. *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem.html*
	**DuPont** Providing protection against a broad range of chemicals and situations involving liquid splash. Tychem® CPF 3 provides at least 30 minutes of protection against over 150 chemical challenges For rigorous activities and rugged situations involving liquid splash *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-cpf-3.html*
	**DuPont** Tychem® F coveralls, are made of a proprietary barrier film laminated to a Tyvek® substrate. Strong, durable, and lightweight, it is a preferred choice for law enforcement, emergency medical services technicians, and

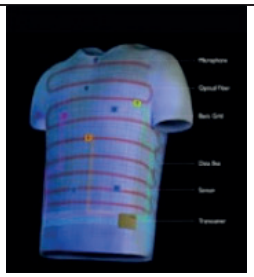
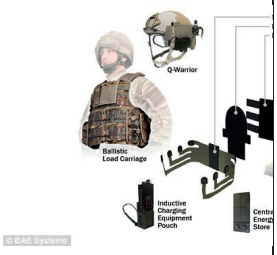
	military personnel. Provides protection against over 180 chemical challenges for at least 30 minutes *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-f.html*
	**DuPont** Low-visibility color for military operations or other situations requiring discretion provides protection in moderate to heavy splash applications with a broad range of chemical protection. Provides at least 30 minutes of protection against over 280 chemical challenges *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-lv.html*
	**DuPont** Protects against light liquid splash with at least 30 minutes of protection against more than 40 chemical challenges *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-qc.html*
	**DuPont** For chemical protection in emergency situations.This unique combination provides excellent physical strength. It's ideal for industrial chemical, HAZMAT response, and military applications, including those that include chemical warfare agents. Provides at least 30 minutes of protection against over 285 chemical challenges

	http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-reflector.html
	**DuPont** Scientifically engineered to handle the challenges of chemical warfare agents, military site cleanup, and HAZMAT first response, provides high-level protection against toxic and corrosive gases and liquid chemicals. Provides at least 30 minutes of protection against over 325 chemical challenges Primarily used for chemical weapon demilitarization *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-responder-csm.html*
	**DuPont** Provides at least 30 minutes of protection against over 120 chemical challenges *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-sl.html*
	**DuPont** Triple-hazard protection from liquid-chemical splash, flash fire, and electric arc. Provides at least 30 minutes of protection against over 180 chemical challenges plus the added benefit of electric arc, and flash fire burn injury protection *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tychem/products/tychem-thermopro.html*

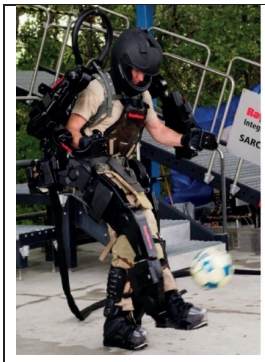
	**DuPont** It has been designed for work in very humid applications requiring chemical, liquid and/or oil protection. *http://www.dupont.com/products-and-services/personal-protective-equipment/chemical-protective-garments/brands/tyvek-protective-apparel/products/Tyvek-800J-coveralls.html*

3.3.5. Prototypes in development process

	**Exosuit** Soft exosuits offer a new way to ease the physical burden of soldiers, firefighters, paramedics, farmers and others whose jobs require them to carry extremely heavy loads. *https://wyss.harvard.edu/technology/soft-exosuit/*
	**TALOS Exosuit** Tactical Assault Light Operator includes embedded sensors for monitoring body temperature, heart rate, hydratation levels and body position; heaters and coolers to regulate the temperature inside the suit; full-body bulletproof armor; 360 degree cameras with built-in in night vision and a powered exoskeleton. It is expected to be ready by 2018. *http://www.techtimes.com/articles/92478/20151007/u-s-military-to-deliver-its-first-bulletproof-weaponized-iron-man-suit-in-2018.htm*

	**Bionic Power** Wearable technology for charging batteries - PowerWalk® Kinetic Energy Harvester for military use. The light-weight PowerWalk harvester is designed to generate electricity from the natural action of walking. With every stride, the harvester's on-board microprocessors analyze the wearer's gait to determine precisely when to generate maximum power with the least amount of effort. The PowerWalk's gearbox converts the knee's rotational speed to a higher speed for efficient power generation and a generator converts the mechanical power produced into electrical power. A state-of-the-art power-conversion circuit then converts the electricity to recharge Li-ion or NiMH batteries. *http://www.bionic-power.com/*
	**Sensatex** The Sensatex SmartShirt was designed to make fast diagnosis and quick responses to medical emergencies. The idea was to create a shirt that transmits data from the wearer, without hindering his or her movement. *http://www.sensatex.com/smartshirt_hm.html*
	**BAE Systems** A vest called Spine uses so-called e-textiles to wirelessly charge military equipment - and this energy use can be monitored using a smartphone app. Other equipment in the range includes the Q-Warrior augmented reality headset and car seats that wirelessly charge the wearable technology. *http://www.baesystems.com/en-uk/product/broadsword-spine*

	**BAE Systems** BAE Broadsword power and data distribution harness, which uses e-textiles embedded within the uniform. *http://www.baesystems.com/en-uk/capability/research--design---development*
	**Elbit Systems** Smart Vest system for BENELUX countries for their soldier modernisation programmes. http://elbitsystems.com/about-us-major-activities-military-aircraft-and-helicopter-system/
	**Intelligent Textiles Ltd.** Bulletproof vest
	**Intelligent Textiles Ltd.**
	**Intelligent Textiles Ltd.** Fabric keyboard

	**Prototypes of exosuits**
	**Prototypes of exosuits**
	**Prototypes of exosuits**
	**Exoskeleton** The exoskeleton is a wearable bullet-proof robot, sensing where a soldier intends to go, and then accelerating that movement using its titanium frame working on batteries. It facilitates running longer, jumping higher, carrying weight and even lifting objects that a man would not normally be able to lift. The exoskeleton allows the soldiers to do more, longer, and harder, without getting as tired. *http://techiewear.blogspot.com/2014/04/military-wearable-tech-iron-man.html*
	**Second skin** New material that is breathable and protects against biological and chemical threats. This futuristic material or 'second skin' will offer more protection for our warfighters in contaminated environments by sensing and reacting to chemical and biological threats.

	https://www.dvidshub.net/news/210945/futuristic-smart-uniforms-protect-nations-troops

4. PROTECTION AGAINST INSECTS FOR MILITARY REQUIREMENTS

Anti-insect clothing provides protection against insect attacks. Military clothing for insecticidal fabrics has been in use for more than 45 years, research and development in this area will continue [113]. One of the initial ideas for the production of such textiles was the production of clothing for long-term protection of children in insecure areas [114].

Clothing made of insecticide textiles provides lasting protection against insect attacks from 25 up to 70 washings of clothes, depending on the clothng technology and the composition of the clothing solution, or retains the effect for up to 10 years, taking into account the wearing frequency of the clothing. The most commonly used synthetic repellents such as permethryne or DEET (N, N-diethyl-m-toluamide) or naturally occurring plants such as lemon grass or citronella are most commonly used as a substance in the clothing [115]. This wearer wears protection against mosquitos, ticks, bats, antches, claws and mosquitoes that can not only create discomfort with their presence and stings but also infect a person with the dangerous infectious diseases they carry [114].

The following clothings are easy to maintain. Clothing manufacturers guarantee persistence of the substance if the clothing was washed at 40 ° C using a detergent. But it's not advisable to clean such clothes chemically because it interrupts the effect of apretion by reacting with the cleaning agents repellent that is in the form of the apret, thereby reducing the effect on the insects [116].

Anti-skins wearers and others do not have to worry about negative health effects. Insecticidal clothing is used as a repellant for the use of substances such as permethrin, DEET, citronella extract, which are also used for the production of anti-insect spray aerosols. Repellents are not harmful to humans if they are used in a reasonable and proportional manner, for example, not to be used to protect infants from insects, children and pregnant women, with a lower repellent concentration in the protective device. These principles are respected by the producers of insecticidal clothing, manufacturers of aerosols, manufacturers of ointments and gels, supplying the consumer with information, mainly on the packaging of protective equipment.

The use of repellents in the environment does not pose a threat. The use of repellents for the use of insecticide protective equipment is strictly listed when

determining the dosage for the production of the product. And of course, employees who are in direct contact with the use of repellents in the production process must comply with the rules of work safety and must wear appropriate protective clothing.

4.1. Fabric finishing types

In order to protect insects from special tasks (army, police and other similar structures), textile finishing is used: spraying, impregnation and microcapsulation.

4.1.1. Textile sprying

Textile spraying is one of the dressing techniques. It is a chemical finishing method by which the circadian solution is directed to the surface of the fiber material. In this way, the finish is applied on one side of the fabric, as needed - on the right or left. Using this technology, it is possible to adjust the amount of circulating solution required by applying a very thin layer of solution or by spraying with a stronger spray [117].

This cloth impregnation technology is one of the most economical and eco-friendly. The coating process is fast, where the solution to the cloth is applied optimally without creating excess residues. The mechanical construction of the dressing equipment is also easy [118]. Finishing technology consists of three main stages:

- Cloth spraying;
- Removal of excess dressing;
- Dressing strengthening.

The fabric for finishing is first placed on a spray device where the cloth is treated with a chemical solution. Then the outer overcoat solution is removed from the cloth, if it occurs, smoothing the coating. The last step is to strengthening the dress - drying the textiles.

4.1.2. Textile impregnation

Textile impregnation technology is a common method of cladding. The type of drill handling is relatively simple: the textile material is stored for a certain amount of time in a pre-prepared solution, where the material is absorbed into the fiber in fibers or between yarns [119].

Finishing process takes place in two stages. First of all, the impregnated fabric is placed on a dressing bath in which the solution is made. Cloth feeds at a speed so that

the fiber is able to absorb fluids. The amount of excess dressing from the cloth is pushed through the rollers. Next, the cloth is directed to a drying machine, where, under elevated temperatures, the material is dried and fixed on the occasion.

This cloth is more expensive compared to the spraying method, where the greatest cost comes from the inefficient use of chemical solutions (the residue of the solution is generated during the treatment) [120]. But the cloth in this way keeps the dressing for a longer time, even after several washings [119].

4.1.3. Precessing of textiles with microcapsules

In order to obtain a longer-lasting effect of repellents from insecticidal fabrics, microcapsules filled with anti-inflammatory agent. The use of microcapsules for textile finishing has several important advantages: the design of microcapsules provides for the release of slow repellants; protects the repellant from detergents and water during the care of the cloth; the microcapsule protects the anti-insect from weather effects (sunlight, rain exposure). The effect of the encapsulated substance is observed evenly through the microcapsule wall or the breakdown of the microscopic particles by the repellent.

Microcapsules have a diameter of 3 to 800 μm in diameter, which weighs 10-90% of the weight of the filler or active ingredient. The microscopic particle is a set of filler and sheath [121]. They can be of different shapes - spherical, cylindrical or droplet, depending on their application. Spherical microcapsules, which differ in their construction, are most often used to finish the textiles. The main types of construction are single-coated (filler-resistant coating), multi-coat (a continuous coating covers several separate filler particles) and a matrix type (porous shell microcapsule) [122].

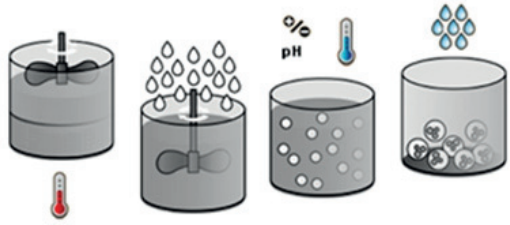
The microcapsule forming elements are filler or active ingredient and coating or membrane. Fillers that are incorporated into microcapsules can be any type of agregate state - gaseous, liquid or solid. In turn, the sheath of the microscopic particles can be permeable, medium-permeable or impervious. The permeable sheath is used to make the substance embedded in this microcapsule evenly distributed under the influence of conditions. In contrast, the medium-permeable capsule moves molecules with the lowest molecular weight through the shell. Such capsules are more commonly used to absorb substances rather than excrete them. The use of impermeable sheathing

microcapsules when the filler is to be removed from the microscopic particles under certain conditions such as light or temperature [117].

When studying the effect of insect-phobic cloth on pests, the use of the most appropriate insecticide for cloth trim is evaluated at the same time. The highest protection is given by N, N-diethyl-meta-toluamide (DEET), synthetic pyrethroid (permethrin), citronella extract, which is incorporated into microcapsules. Prior to the application of repellents in microcapsules, insecticide concentrations are reduced by the addition of distilled water. Substances that are encapsulated in a repellent solution are substances such as melamine, gelatin or gum arabic [123].

Microcapsules for repellents are mainly used for the most widely studied and most commonly used methods - coacervation method. The coacervation method is the first one used for the industrial manufacture of microcapsules [117].

In order to encapsulate the repellents, an appropriate anti-infective concentration solution is prepared, which is heated to 40 ° C. Solution is thoroughly mixed. Once it has reached the required temperature, add a drop by drop to the gum arabic solution that will form the microcapsule shell. The substance is then rapidly cooled to 10 ° C and, adding sodium hydroxide to ensure the alkalinity of the solution (the pH should be 8), gum arabic drops cover the repellent solution by creating microcapsules. The coacervation process is completed by adding distilled water at a rate of 20 $ml \cdot min^{-1}$. The development process is illustrated in 39.fig. The resulting microcapsules are then dried at 90 ° C to give a loose powder. The size of the produced microcapsules is 4 – 5 μm [115].



39.fig. Manufacture of microcapsules containing repellent

The use of microcapsules in insecticidal textiles mainly involves the provision of durability of dressing. The microcapsule provides greater protection for the repellent against environmental conditions, especially precipitation. Since the microcapsules are

only a few microns large, the coating is neither visible nor tangible, and does not in any way contribute to the changes in the characteristics of the coated fabric.

Microcapsule coatings for fabrics can be done in two ways. One way is to impregnate the cloth with microcapsules, the other is spraying. The drum coating is made up of a dressing containing microcapsules, distilled water, adhesives. The microscopic particles containing the reagent powder are mixed with water to form a 15 to 20% suspension, in addition to the addition of adhesives, which help to secure the microcapsules on the surface of the textiles or between the yarns [115].

With a microcapsule dressing, dry textiles are applied by placing it in a dressing bath, holding the material until it is absorbed by the dressing. When spraying textiles, the aprete is applied so much that the cloth is completely moistened. The cloths are then placed in the drying chamber, where they are kept at 100 ° C for 3 minutes [115].

4.2. Methods of testing anti-insect effects

The effects of insect-protective cloths are tested by various experimental methods. In order to test the functionality of insecto-phobic cloths, insect species of different species are selected for experiment subjects. Experiments have been developed to test the effects of material circulation, which can be tested in laboratory conditions or in a natural environment. There are several methods for experimenting with cloth in laboratories, in which the subjects used are specially grown, kept and fed [115].

Experiments in laboratories have more advantages than testing the effects of cloths in a natural environment. In laboratories, all samples subjected to testing are mainly provided with the same conditions, it is possible to make rigorous measurements and obtain accurate results. In turn, when performing experiments in insect-populated areas, the effect of a textile product is tested in the conditions provided for it. Such an experiment does not provide accurate numerical results but expert opinions and evaluations of material functionality..

The ability to repel insect repellents and the duration of exposure can be determined by experimentation. Their results provide information on the properties of the anti-insect coating, under certain conditions of use and against insects of certain species. But it should be borne in mind that insect-phobic coating can not guarantee absolute protection against insects or their bites, just like any protective device.

4.2.1. Insect stunning test

Insect stunning test (eng. *Knockdown Test*) is one of the most common methods of researching anti-insect finish, the use of which has been internationally recognized by organizations such as Pasaules Veselības organizācija (*World Health Organization*), Slimību profilakses un kontroles centrs (*Centers for Disease Control and Prevention*) un Amerikas Savienoto Valstu Lauksaimniecības departaments (*United States Department of Agriculture*) [124].

An insect stunning experiment is the only method that gives results on the durability of repellant finishing. This experimental method is widely used in scientific research. Using this test method, it is possible to simultaneously compare different - both after finishing technology and dressing content, samples of textiles. As a benchmark, the cloth without dressing is used during the experiment [125].

This method is used to determine if the time required to insects is affected by the anti-inflammatory aperture concentration. The study uses specially grown insects, which are placed on a sample of bleached cloths, by contacting only a textile and Petri plate or other experimental equipment, in which it is possible to insert the sample and seal it so that the insects do not leave it [125]. Experiment progress is reflected 40.fig.

40.fig. Insect stunning test process [124]

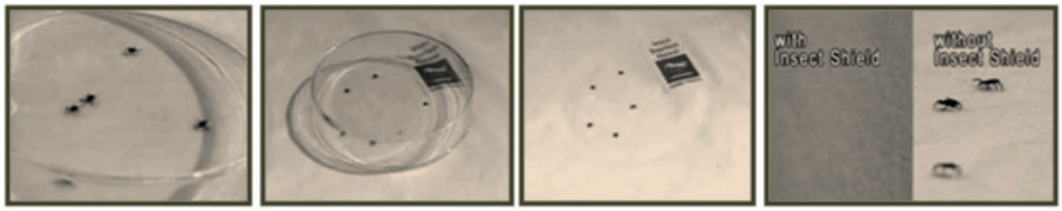
When a sample is placed and insects are in contact with it, a time report is started. Depending on the nature of the experiment, to observe the resistance of the insects or the effect of the cloth, the time for admission is made in two ways: it records the time when all the subjects of the experiment are dead or the sample with the insects holds a certain number of minutes (10 min, 15 min, etc.), then observing, how insects are stunned, how many live and dead insects. In this way, check the durability of the coating for the samples, only after each experiment, the textile is washed (all samples are washed in the same mode). Applying repellant dressing is washed at low water temperatures of 30-40 ° C, with detergent. Sample washing takes about 10 minutes, then rinsing the sample [125].

After testing the samples, the results are analyzed by analyzing the effects of washing cycles on the stability of the circulation.

4.2.2. Tick test

Testing the insecticidal cloth with a tick test is just as necessary as an odd test because the prevalence of ticks is increasing rapidly. The active substances contained in the various repellents are unpleasant for ticks; therefore their movement in contact with the anti-insect coating becomes uncoordinated and looks as confused.

This method determines whether the cloth is dressed or not. Tick can very well move on different surfaces (glass, tree, plant leaves, also textiles) due to their construction. But if the material is treated with insecticide, the tick-bone glands penetrate the molecules of the repellents, blocking them, which make it difficult for a tick to move. The longer they stay on dressed textiles, the slower they will become and soon die. 41.fig. illustrates the experiment's progress [126].



41.att. Tick test precess [124]

4.2.3. Arm-in-Cage test

The Arm-in-Cage test is a quick and beneficial way of detecting scouring properties of treated textiles. It is ideally suited to the product manufacturing process. Repellant exposure tests with crop tests are recognized and effective in research because the subjects of the experiment are attracted by the heat emitted by the human arm on which the glove with or without apportionment is exposed. The experiment proceeds as follows: volunteers are covered with a piece of the body (most often the palm and forearm) with a textile product and then it enters the cage where there are specially developed insects for experiment. The effect of the material on the insects is observed by examining both rough and uncoated material (see 42. fig.)[126].

42.att. Arm-in-Cage test precess [124]

Using this test method, products with a variety of anti-reflective finishes, such as an unbreakable glove, spray and impregnated, are selected for testing. The effects of the repellents are measured on each human being's wrist and placed in the chamber (most often 50x50x50 cm big), where the mosquitoes are located. During the experiment, the relative humidity of the air is maintained at 80 ± 5% and the air temperature is 26 ± 1 ˚C. The glove in the chamber is held for 1 minute, which contains about 200 oviduct females, which are not fed for 3-5 days. Experiment progress is monitored by 2 independent actors and is photographed as well as fixed observations by observers that, during the test, count odors lying on the surface of the cloth. The experiment is performed with each sample every 5 minutes and every few days, as needed [115].

Collect the results and calculate the percentage of insects landing. The test provides for opaque imperfection, which is to be understood as the mean number of insects per head on the cloth. Experimentally, there are 3 types of cloths, but controls include bare palm testing. The test results indicate that the raw cotton cloth provides some protection during the whole experiment compared to the bare palm [115].

4.2.4. Field test

The experiment, which most accurately reflects the effect of apretion, is an examination of the functionality of insecticidal clothing in the field test. This test method provides clear and obvious results for the effects of insects on anti-insect crafts in textiles. Experts are volunteering who gets involved in the experiment and provides an insight on the suitability of clothing for insect protection.

Exposure controls in the environment occur in different weather conditions, where the effects of repellents can be observed on several insect species at the same time. The experiments are mainly based on places that are abundantly inhabited by insect species, such as at or near water bodies, in the wilderness. The course of the test method is illustrated 43.att.

43.fig. Experiment process of the product in field test [124]

4.3. Use of protection against insect (Estonian partner experiance)

Defence Forces (DF) wants to use for everyday summer uniforms material (not for combat or special units) with anti-insect treatment. Especially against ticks.

Company purchased the fabric with permanent anti-insect treatment, sew the samples and gave to soldiers for testing. Feedback was very positive. Then DF started to develop the subject. The new fabric is different from previous, light (195 g/m2), RipStop, 50/50 % cotton/ PA 6.6 Nylon T420 HT with very good characteristics of strength and abrasion. From here rised the question: will it change and if does then how much the permetrin anti insect repellent used change fabric characteristics will.

Profline gained info about the properties of permetrin (allergic, etc) and sent to DF doctors for peruse. Also different treatments/repellents of fabric were discussed (teflon, nano, carbon jne.), but there is no knowledge how much they influent on fabric's air permeability. All „abilities"cannot be summarized.

From that point started testing in TTK.

Lai noteiktu pretinsektu apstrādes ietekmi uz drānu, tika veikta testēšana:

- Abrasion test - Determination of the abrasion resistance of fabrics by the Martindale method.
- Pilling test - Determination of fabric propensity to surface fuzzing and to pilling (Martindale method).
- Tear test - (Determination of tear force using ballistic pendulum method (Elmendorf).
- Tensile properties of fabrics - Determination of maximum force and elongation at maximum force using the strip method).

Air permeability was not tested yet, so the survey on this issue should be continued.

5. BUILDER WORK CLOTHING MANUFACTURING FACTORS

Describing the specifics of work design design, one can consider the main factors in designing the design of clothing systems, which are: protection, comfort, mobility (or ergonomics), connectivity (or compatibility) and ease of use (or functionality) [127]. The following text describes how each of these factors should be understood and how it relates to work clothes for builders to be developed.

5.1. Comfort

The comfort is to be seen from the point of view of the ease of movement, which is traditionally associated with this concept, and is related to the human thermal comfort at both lowered and elevated temperatures. It is customary to determine thermal comfort according to the sensation of heat and skin temperature. A person feels the warmth of comfort when the average weighted skin temperature is 31-34.5ºC. At temperatures below 31 ° C, a person feels an unpleasant feeling of cold [128]. In order to ensure the builder's thermal comfort, the work environment must be taken into account both during summer and winter conditions, paying particular attention to the selection of materials from which work clothes are made.

It should be noted that since 1973, when Professor O. Fanger's research on thermal comfort has been published, it is known that it is impossible to speak of a microclimate that would be equally suitable for all individuals, because the thermal comfort is influenced by individual peculiarities that can not be generalized. Given that one can not concentrate on ensuring the comfort of each of the equal working conditions, it is to be limited to establishing the conditions that would be acceptable to most workers.

5.2. Mobility or ergonomics

Terminological mobility can be explained by mobility, movement, which is an essential aspect of the design of work clothes. The free movement of dressed human beings depends on both the applied cloth and the design. Heavy fabrics will affect the wearer's ability to work because the wearer must wear clothing that increases energy losses. A considerable part of the weight rests on the shoulder of the wearer, and the muscular mass of the trapezoidal shoulders has the greatest load, causing a similar load to it as if the backpack is on its shoulders. Clothing design is equally important.

Anthropometric measurements in static positions are traditionally used in design, but when designing sports and special clothing, changes in dynamic body measurements should be taken into account [127]. Providing ergonomics for construction workers' workwear is reflected in the choice of model designs and materials.

5.3. Connectivity or interoperability

Connectivity is explained in a variety of industries as a system or device-specific property that allows it to be added to other systems or devices without modification. In this case, in the context of the subject under consideration, a single article, when put up with other parts of the outfit, should not disrupt the overall design and function of the clothing. This is the essence of connectivity that must be respected in all aspects of the clothing. This means that the elasticity, weight, absorption and vapor permeability of the fabric, and possibly other characteristics of the various layers of clothing should be carefully completed. This is especially true in terms of providing functions such as vapor permeability [127].

The connectivity or interoperability of the wearer's clothing must be consistent in preserving the protective functions without making additional modifications. Particular emphasis is placed on the requirement for increased visibility when wearing clothes in different combinations.

5.4. Ease of use or functionality

When designing different items of work clothes, several conditions must be taken into account in order to avoid additional problems for the person during operation.

For example, the way to wear and pull clothes is an important aspect of goodness. Generally, two-piece clothing is easier to use as a single-piece (overalls), since they provide greater freedom of movement. Anoraks-type jackets that need to be pulled overhead are impractical for jackets with buckles at the front, all the more so when wearing a helmet or respirator [127].

When designing fasteners for zips, it is considered serviceability and recovery possibilities. The same applies to plastic fasteners, push buttons, grapples, etc., these elements may lose their properties in snow and frost conditions. For the cold weather, the fastening elements must be sufficiently robust to be gripped with gloves [127].

Pockets are discrete elements. Users often require more pockets as needed. In addition to work items, there is also a need for personal items such as mobile phones,

notebooks, pencils, documents, pocket scarves, keys, glasses, cigarettes, lighters and other things. When pouring extra clothing on top, you must be able to access the pockets in the bottom layer through the openings in the outer clothing [127].

5.5. Protection

The construction work takes place under conditions of high danger, taking into account the location between building structures, the presence of health and life-threatening substances, the effects of weather conditions on the human body during the summer and winter seasons, and the impact of high workloads and applied tools on the human body.

To initiate risk types and volume exposure assessment, a risk assessment procedure should be initiated. For each of the occupations (posts), the types of risks may vary, which will also affect the materials used in work clothing, the selection of clothing elements and their assemblies, possibly also creating cost differences.

Procedures for risk assessment at the workplace:

1) Determine the risk factors of the work environment, including their causes and sources;
2) Identify the employees or other persons whose safety and health are exposed to the work environment risk;
3) Evaluate the extent and nature of the work environment risk. Some can be evaluated locally - most of the traumatic factors, the order of the working environment, the reliability of the work execution methods, and so on. etc.;
4) Determine which labor protection measures are necessary to prevent or reduce the risk of the work environment. Measures - both engineering, organizational and labor protection.

In general, personal protective equipment is considered to be such devices as eyeglasses, respirators, gloves or similar products, but also protective clothing is an essential component of personal protective equipment. There are various types of protective clothing: against mechanical injuries; in the face of heat and fire (infrared radiation); in the face of chemicals and chemical products; facing low temperatures (thermal protective clothing); facing biological risks; in the presence of radioactive substances ionizing and non-ionizing radiation; well-visible protective clothing (fluorescing or reflective); in the face of electrical risk; antistatic protective clothing.

In order to protect against adverse effects, it is important to know precisely and to apply the rules for the use and design of protective clothing. Some guidelines for wearing protective clothing related to construction worker clothing:

1) The ends of the sleeves and trouser rays must fit into the body, the buttons must be tightly polished and closed with pockets;
2) Special clothing should be inspected regularly to ensure its perfect condition, make the necessary corrections and properly clean it;
1) To plan timely replacement of clothes;

For clothing, which ensures greater visibility of the worker, the UV-radiation of the sun will eventually reduce the fluorescence of the garment's fluorescence layer. As soon as this outfit has got a yellow color, it should be discarded immediately.

Also, maintenance is considered as an important aspect of protective garments. Some maintenance tips:

1) Only precise compliance with the washing and storage instructions provided by the manufacturer guarantees a consistent level of protection;
2) When repairing protective clothing, only materials that have the same characteristics as protective clothing should be used;
2) If the reflective dresses become dirty, they lose their visibility very quickly. Therefore they should be cleaned regularly.

As an individual remedy for builders, clothing and footwear, as well as other ancillary items, for example, for the protection of eyes, face, respiratory system, hearing and hands, are used. In order to protect clothing and other personal protective equipment from all risks in the work environment, all occupational risks must be precisely assessed prior to their purchase by the labor protection specialists and detailed product protection requirements for their manufacturers or suppliers. The work responsibilities of the employees of different departments and, therefore, also the risks are different, therefore, a system is needed, in which, according to each post, protective clothing requirements are specified. In this way, it is possible to structure the clothes and the materials used for it, so that the production of clothing for all employees would not require the same and at the same time the highest protective properties, thus increasing the total cost.

5.6. Summary of functional requirements for builders' clothing

General functional requirements for construction workers' working clothes, which are guidelines for the design of work clothes for builders:

1) Ensure increased visibility.
2) Ensure that the body is not detached during movement.
3) Protect against the adverse effects of the sun, wind and precipitation.
4) Protect against oil products and dirt.
5) Ensure comfort during work time, preventing the wearer from losing body temperature, sweating or overheating.
6) Ensure that the protective properties of clothing are maintained for all the time required to wear.
7) The mass of the product must not impair the wearer, it should not adversely affect the wearer or cause injury (rubbing, scratching, blocking the blood, etc.).
8) Clothing should be easily stretched and legible.
9) Clothing should be provided with freedom of movement. For jackets - especially in the back and sleeve areas. For trousers - knee and seat areas. Puskombinezonos - in knee, wing and seating areas.
10) Tactile, uniformity, dimensional stability, durability and durability properties of products must be consistent with the appropriate level of quality for all intended wearing time.

5.7. Survey of existing wearable technologies and needs of builders (experience of Polish partners)

A presentation was prepared, was presented at the partner meetingat KRYSTIAN company. During the meeting about 30 examples of solutions were presented. Among the discussed next-generation textiles solutions using multifunctional smart materials including: "wear" electronics, intelligent materials, electronic components for automatic data identification, including RFID technology, to: monitoring of physiological functions and/or changes in environmental conditions, alarm of danger and health protection, the following examples are given:

- workwear made of reflective materials including light signaling, optimizing visibility,

High-visibility workwear

a) 

b) 

c) 

a) http://www.snickersworkwear.com; b) http://mammothworkwear.com;

c) https://www.hhworkwear.com

Workwear with integrated LED lights

a) 

a) Safety vest – with Light Flex active light

https://www.hhworkwear.com

b) 

b) Reflective safety vest with led light. LED color: white, red, green, blue, orange. Flashing mode: Stable bright, quick - slow flashing. Removable usb rechargeable 550mA Lithium battery.

http://www.wildsaver168.com/

c) 

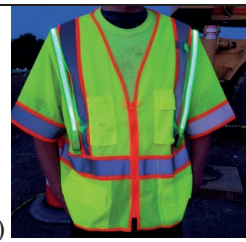
c) Reflective safety vestwith led light.

http://www.wildsaver168.com/

d) 

d) Front lights, lighting on shoulders (white light).

https://www.light-vest.com/

e) 

e) Illuminated safety vest. Strips - USB rechargeable, charges in 1 1/2 hours, run for 8-10 hours on time.

https://nightlightsafety.com/

- heating clothing with the use of electronic systems along with various methods of power supply,

Heating clothing

a)

a) Infrared Carbon Fiber Heating. Core warming zones on chest and back. Powered by 3400mAh capacity lithium-polymer battery, rechargeable over 300 cycles. Power：19W max.

http://www.ele-heat.com/productshow-27-72-1.html

b)

b) Small 7.4V 4400mAh Li-Ion battery with a USB output that can also recharge your mobile device, recharged in ~3.5 hours providing a jacket heating run time of up to 8 hours when fully recharged.

https://www.kincrome.com.au/jacket-heated-hi-vis-medium

c)

c) 20-Volt/12-Volt Heated Jacket with Lithium-Ion Battery and Charger

http://www.homedepot.com

d) 

d) Cordless heated jacket powered by Makita 14.4V or 18V Li-ion battery.3 heat zones: Left chest, Right chest and Back.On/Off heat controller with 3 LED's on left chest for notification of heat level setting. Back pocket on left side: For Li-ion battery and battery holder.Removable battery holder. Jacket can be seperated from electric power source for hand washing.
https://www.datapowertools.co.uk

e) 

12 V Max heated jackets, rain and wind resistant, powered by the Bosch 12 V Max power tool battery system. Three simple push-button heat settings - high, medium and low. With the included BHB120 and a Bosch 12 V Max battery can also power most USB port compatible personal electronics. https://www.boschtools.com

f)  

f) Heated Hoodie

http://www.ele-heat.com/productshow-27-72-1.html

g)  

Heated Neck Guard

Far infrared Carbon Fiber Heating. Core warming zone: neck. Power5W. Material: neoprene. Machine Washable in Washing Bag. Temp. MAX 45^{O}.

http://www.ele-heat.com/productshow-27-72-1.html

h)    

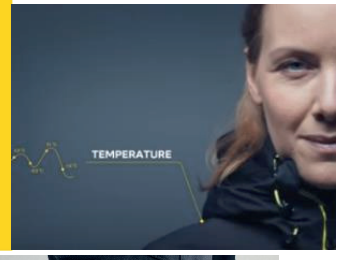
h) Heated belt andgloves

http://www.ele-heat.com/productshow-27-72-1.html

- sensors that monitor the operating environment, including: outdoor temperature, oxygen level, concentration of harmful gases, radiation level,
- specialist clothing with built-in: electronic compass, integrated altitude and latitude sensors (GPS module),
- applications of Automatic Identification Data, including: bar codes, RFID sensors, biometric systems,
- power ways of the textronic systems.

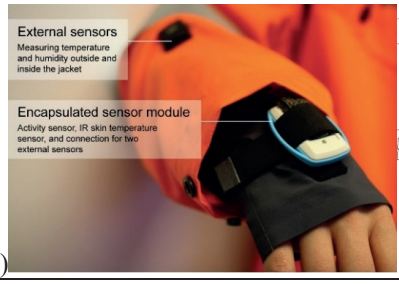
Concepts of smart workwear

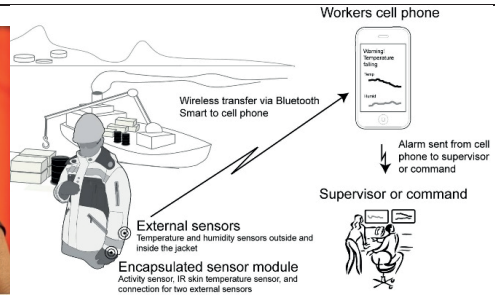
a)



a) In 2016 Snickers Workwear launched a test in which 100 craftsmen across five countries work in trousers featuring wearable technology measuring their performance
http://www.snickersworkwear.com

b)

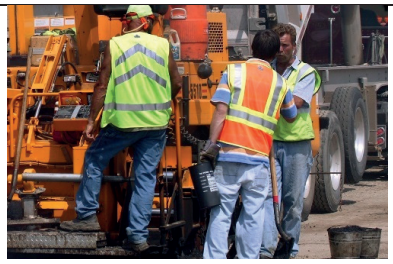




b) Smart protection of hands in the cold - indication of critical level of cold.

Jacket with integrated wireless sensor system.

https://www.sintef.no

c) 

c) Smart Vest. Developed by Human Condition, geared towards the safety of those working in the construction industry. Wearable technology that can track users whereabouts on a job site, while at the same time provide information about the impacts felt by the user and determine if an accident has occurred. Also has the ability to gather information and integrate with BIM software and provide a 5-dimensional view of a construction project. Allows users to track time, climate, materials, and workers and use this information for modeling purposes and to develop predications about when projects will be completed.

http://www.builtr.io/ten-innovative-wearable-technologies-for-the-aec-industry/

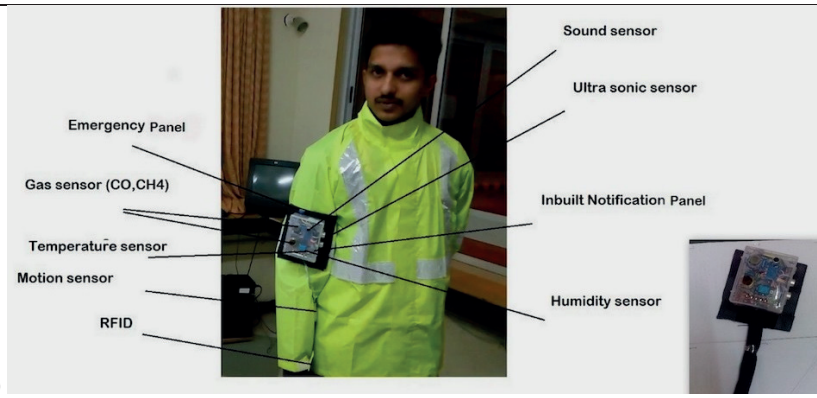
d) 

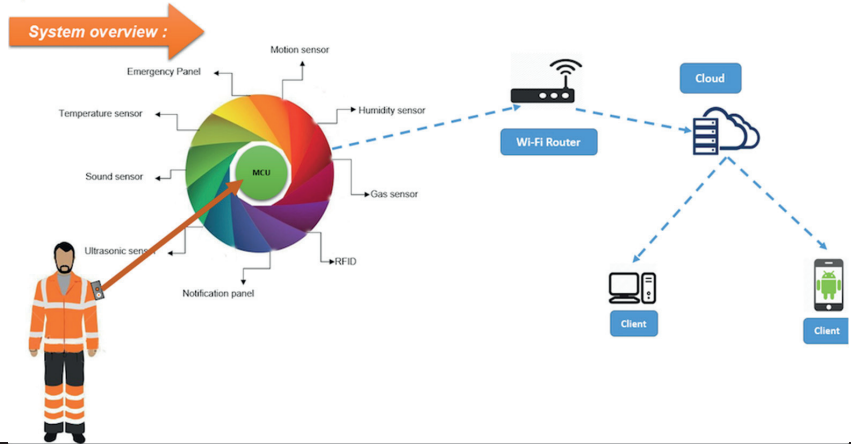
d) Smart Wearables and Sensors. Smart Protective Clothing

Include gas, chemical, heat, sound, uv, impact and pulse sensors, along with an LED indicator light. Comes with internal and external temperature sensors to prevent overheating or cold exposure.In case of any danger, the complimentary app alerts users in time to prevent any harm.

https://seebo.com/smart-protective-clothing-concept/

e)

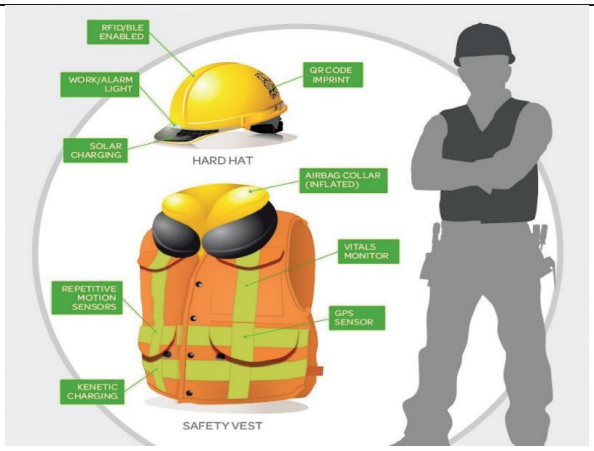




e) Smart Safety Jacket is an IOT technology based device used for safety purpose of the employees who work in mining site and construction site.

Jacket is connected with the different type of sensors: Temperature Sensor, Humidity Sensor, Ultrasonic sensor, Motion sensor, Gas sensor, Sound sensor, RFID, Emergency Panel, and Notification Panel. Sensors connected to the network through wi-fi, the information can be monitored through an ISO android app and personal computers.

https://contest.techbriefs.com/2017/entries/electronics-sensors-iot/8153

f) 

f) Human Condition Safety (HCS) is creating a suite of tools that helps workers and their managers prevent injuries before they happen. Incorporating wearable devices, artificial intelligence, building information modeling and cloud computing, the product suite is designed for the industries that hold the highest risk for workers, including manufacturing, energy, warehousing and distribution, and construction. http://www.hcsafety.com/

From the initial examples presented, the interest of the Management Board of Krystian has aroused by the RFID technology, so IW made a thorough analysis of information on the types of sensors in the world market, their drawbacks and advantages, physico-mechanical properties, the length of their reach, their application and implementation possibilities in the garment, their power supply, their prices. The informations and contact to manufacturers and distributors were given to the production company as well.

Finally the Krystian Company selected and purchased sensors using RFID technology to automatically identification data it is tag RFID to mark and identificate end users work wear.

CONCLUSIONS

A communication system for communication between two smart clothing consists of data transmission and data capture - imaging systems. Sensors capture data on the wearer's physical or environmental physical or chemical processes, which, after processing, are sent to the transmitter. Radio waves emit and receive through the communication channel by antennas. The transmitter receives the receiver data and processes it according to data display devices. Smart clothing use displays for monitoring functions. The data transmission system signal can be received by an unlimited number of receivers that are interoperable with the transmission system.

Integrating electrical conductive components into textiles is a way to provide lightweight, comfortable, flexible and smart smart clothes. Weaving and knitting technologies are used for manufacturing textile tapes with conductive properties. Sewing technology can be used for textile conductive tracks, but embroidery is suitable for the development of conductive areas for the manufacture of touch sensitive sensors. In the world, research is being carried out on the application of flexible printed schemes to textiles; however, one of the problem areas is the negative impact of dependency on the conductivity of integrated conductors and elements in the cloth.

The development of smart clothes with the data transmission function in the military and rescue services, in the medical and sports fields contributes to the perfection and development of new technologies.

The information provided in the report and examples of use allow further research to be developed as well as use of existing information to ensure the use and safety of other areas of work clothing smart technologies.

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SMART CLOTHING

- Survey of existing wearable technologies and needs of end-user segments

In this report, we will focus on some of the technological solutions and materials available in the market that is capable to satisfy needs of chosen end users as smart wearables in work wear. Before choosing those technological solutions several factors were considered. It includes, comfortless of the users with integrated sensors and tags, ability to withstand several washing cycles with integrated stretchable electronics technology, resistive to chemical industrial work environment, wireless connectivity to some applications or control system, compatible to extreme environmental conditions including heat, water, different toxic gases, stretchable conditions etc. Figure 1 shows the possible technological solutions in different part of work wear.

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