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APRIL
2020

STATE-OF-THE ART REPORT

context

Smart textiles for sportswear and wearables (WG5)

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

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ABSTRACT

The aim of this document is to provide information on the state-of-the-art related to the topics covered by each working group within the CONTEXT project. It provides information on materials and technologies used to develop smart textiles with targeted performance, general applications of smart textiles in the field, case-studies on the use of smart textiles, opportunities for smart textiles considering the needs of each field, trends on the development of smart textiles in terms of market and technical expectations.

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1. INTRODUCTION

Smart textiles are defined as textiles (in the shape of shirts, socks, shorts, belts, etc.) that can sense and react to environmental conditions or stimuli, from mechanical, thermal, magnetic, chemical, electrical, or other sources to provide functions[1] such as health monitoring and activity tracking. They are able to sense and respond to external conditions (stimuli) in a predetermined way.

Smart textiles for sportswear and wearables have been at the centre of the textile research interest for the last years and numerous national and international programs have given impressive results.

Smart textiles for sportswear and wearables have also generated very interesting interactions between various branches of engineering such as electrical, electronics, telecommunications, micro-nanotechnologies microchips, mechanical, textile, chemical, materials, biology, physiology and physics etc. However, over the last years, although it was expected that the technology developed at the research labs would have shifted to pass into the application and industrial level, a delay has been observed. Smart clothing is already becoming popular among the younger generation of sports professionals. For example, in the 2018 Winter Olympics, smart suits manufactured by Samsung were used to measure skaters' postures in real-time.[2]

It is expected that products based on smart textiles principles for sportswear and wearables will be increasingly seen in the market for general consumers in 2019, even though, currently, only few examples can be found, and not all of them associated to a and also without considerable financial success. It has to be distinguished between professional sports applications and consumer oriented sports. Furthermore Smart Textiles in sports might support athletes in comfort, preparation, monitoring, undertaking and rehabilitation. Professional athletes might have a different focus on several of these aspects that consumer oriented sports.

Smart textiles for sports have a potential to bring a dramatic change in the way athletes at all levels train. Most major sports already started taking advantage of the growing use of technology.

Although it is still an emerging area, several products have already been introduced to the market, and the number of those is growing. In this domain, Europe is reported to be particularly strong in research, product development and prototyping, including the integration of electronics into textiles. When it comes to manufacturing, at this point, it is still at a small scale in Europe, as it is also in other world regions.[3]

Personal injuries are all too common for amateur athletes and sports enthusiasts. A staggering $33B was spent treating sports injuries for young adults in 2014. A key insight from this data is that more than 50% of the injuries were preventable and the smart clothing products can do it.[4]

2. SMART TEXTILES FOR SPORTSWEAR AND WEARABLES

Smart sportswear promises to offer effective solutions for wearers who seek more detailed data about their fitness and performance. Smart fabrics can also increase the comfort level of the user and eliminate the use of bulky equipment such as chest straps. Since athletes and major league players constantly strive to improve their performance, an opportunity of storing data for analysis by lightweight devices that can be embedded in their sportswear offers a high potential for further performance enhancement.[4]

Specifically, technology-enhanced sportswear, including compression garments designed to and muscle recovery, can provide an appropriate medium for carrying large numbers of sensors close enough to the wearer's skin, to pick up the weak electrical signals generated by physical effort. Multiple extra data types, in addition to heart-rate electrocardiogram (ECG) signals, can be collected today, including electromyography (EMG) for analyzing muscle activity.

Furthermore, accurate body-temperature monitoring can be useful for monitoring fitness and can also protect the wearer against the dangers of over-exercising.[3]

Scientists are also working on the opportunities for measuring Galvanic Skin Response (GSR) using electrodes placed against the skin to assess athletes' emotional responses to training routines. However the use of GSR in sports training currently is at the very initial level (a reference design for a wearable, mobile Galvanic Skin Response (GSR) system already exists).

Close-fitting sportswear represents an ideal base for embedding sensors such as MEMS inertial modules, to accurately monitor the wearer's movements. Smart fabrics allow accurate sensing by helping eliminate noise that looser-fitting garments could introduce by moving relative to the wearer's body. Sensing motion enables applications allowing to identify areas where technique could be improved, such as running stride or arm action. A number of products with the motion sensing functions are already on the market.[3] Another development refers to smart heating and cooling systems that allow sustaining an optimal body temperature.[5]

Finally, smart clothing products for sports have the potential to reduce or eliminate most of the preventable injuries. Furthermore, applications having big data capabilities might be able to predict injuries before they happen, based on predictive analytics.[6]

To summarize, smart textiles for sports could potentially bring a dramatic change in the way athletes at all levels train. They promise to transform sportswear into smart garments that can take on the role of personal coach.[3]

E-textile is a multidisciplinary domain, bringing together different scientific and technological expertise with broad application areas. This makes it a challenging domain with a large market potential.

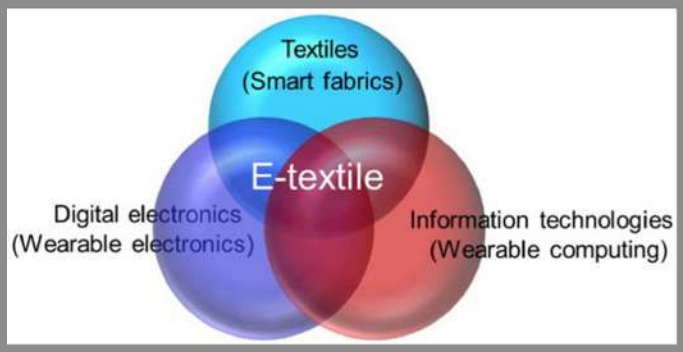

Figure 1 - K. Mondal Interventions, 2018, 3, 23; doi:10.3390

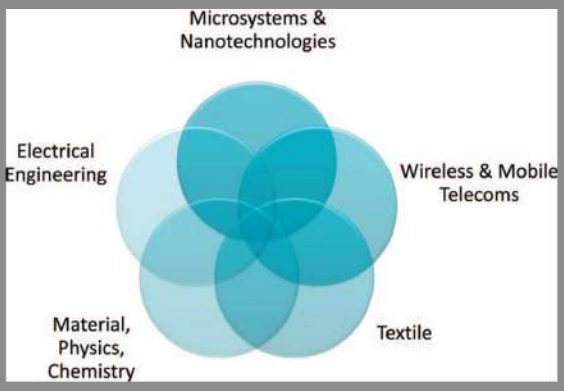

Figure 2 - A. Schwarz et al., Textile Progress Vol.42(2), 2010m 99-180

Market potential estimates (2016):

- 1.8 billion US$ in 2021 (smart and functional like antimicrobial)[7]
- 134 million US$ of sensors in smart textiles for sports, mostly pressure sensors[7]
- Medical 55,5%, percentage in sport, fitness, military, architecture, ... not given %[7]
- From 700 US$ in 2014 to 7.73 billion US$ in 2023[8]
- Market share 30% Europe, 40% North America[8]
- Growth in sports and fitness 2015 to 2023 forecasted 33.1 %[8]
- Healthcare 18,5%, military and defense 28%, percentage sport and fitness not given[8]

Other estimates are given for Europe specifically (2014-2024 in million US$ (2015)):

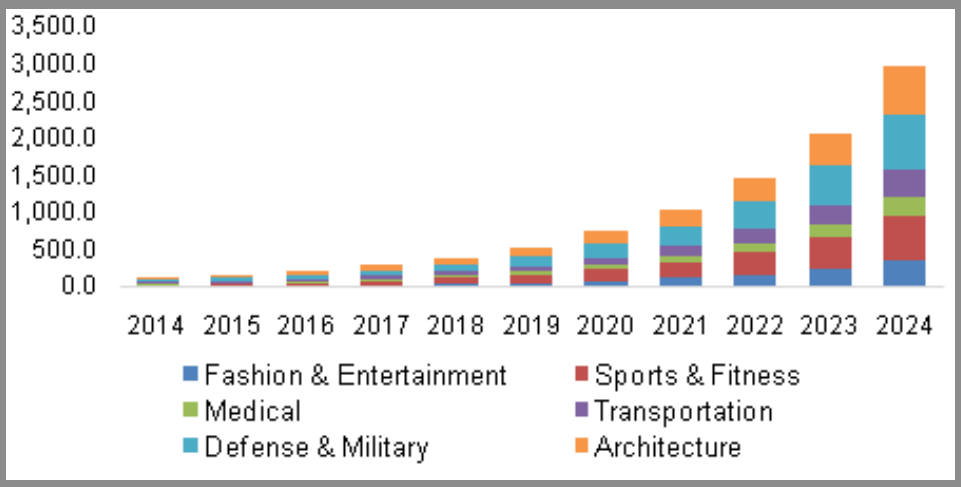

Figure 3 - Market potential estimates 2016

- Smart fabrics and smart textiles 544,7 million US$ in 2015 globally[9]
- Market share Europe more than 30%[9]
- Growth in sports and fitness 2014 to 2024 forecasted 35 %[9]
- In 2015 passive smart textile to dominate the product segment[9]
- Future smart fabrics possess the ability to react to stimuli generated from electrical, thermal, chemical, mechanical, and magnetic sources[9]
- R&D activities in intelligent textiles (including EU supported) help revitalizing industry[9]

Goldstein Research[10] analyst forecast that the global smart clothing market size is set to reach USD 1175 million by 2025, growing at a CAGR of 29.3% over the forecast period (2017-2025). On the basis of functions, biosensors acquired largest market share of 48.7% in 2017. Based on geography, North America accounted for largest market share of 36.2% in 2017 of the total global smart clothing market.

The global smart textile market size is expected to reach USD 5.55 billion by 2025, registering a CAGR of 30.4% over the forecast period, according to a new report by Grand View Research, Inc.[9] Sports & fitness segment will register the fastest CAGR over the forecast years. North America accounted for over 47% of the overall share in 2018, thus, leading the global market and is likely to maintain the dominance even duringthe estimated period.

Global Smart Textile Market size is expected to reach $5,369 million by 2022 from $943 million in 2015 at a CAGR of 28.4% from 2016 to 2022.[11] North America was the highest revenue-generating region in 2015, which is expected to grow at CAGR of 27.9% during 2016 to 2022.[11] Moreover, North America is expected to maintain its dominant position over the forecast period.

Important market drivers for smart and functional textiles in sport and fitness are:

- Decreasing manufacturing costs of electronic components and fabrics along with the miniaturization of electronics are expected to drive the market over the forecast period.[9]
- Increasing demand for heart rate monitors, motion sensors and step counters because of awareness about healthcare and personal wellbeing.[12]
- Increased performance of athletes.[12]
- Developments/innovations are applicable in other sectors as well (military, automotive, entertainment, rehabilitation).[9, 12]
- Nowadays driven by innovative start-ups, SMEs as well as companies like Nike, Adidas, Wacker Chemie, DuPont, Google, Microsoft.[9, 12]
- Important role in the collaboration of industries with universities and research institutes.[10]
- Technology has experienced continuous and advancements in recent years mainly due to disruptive growth in the fields of IoT, flexible electronics, smart materials, low-power computing and networking. These advancements have reduced barriers to technology accessibility, integration and the cost of devices that can be comfortably worn on the body. More in details, specific technology drivers in smart and functional textiles in sport and fitness involve:[5]

  - Innovations in (conductive) materials (polymers (phase change materials (PCMs), stimuli-responsive polymers (SRPs), shape memory polymers (SMPs)), inks, coatings), advanced fibers or yarns, nanotechnology,
  - Smaller, low-power sensors and actuators
  - From smart integration in yarns and fabrics, and attaching sensors, batteries and interconnections towards next generation smart textiles (fully integrated, not visible)

  - Progress in printing (digital printing, like inkjet, 3D printing, Chromojet) and braiding facilitates the next generation of smart and functional fabrics
  - 3D Body scanning for individualized smart garment (integration of production)

- High number of potential smart functions: e.g. EMG, ECG, movement sensors (MEMS) / caputure, GPS, humidity sensors, temperatures sensor, accelerometer, heating and cooling systems, display i.e. as warning systems in traffic, UV-blocking or warning, antimicrobial, odor control, water repellent/proofing, color change, energy production, energy storage, communication, antistatic, Galvanic Skin Response (GSR), eliminate noise, and reduce or eliminate the preventable injuries.

  High cost and lack of awareness are the major challenges hindering the growth of smart clothing in various segments of population.
  The major restraint for the smart textile market is the high cost of production. Smart textiles require high-end materials and are highly sophisticated due to which perfect cost-price balance is not achieved by manufacturers. The market is hindered due to the cost of electronic devices and components, which further increases the prices of the smart textiles.

  The masses are unaware of these technologies and their benefits. There is lack of promotion of product and its advantages, causing unawareness among the potential population.

  Data privacy and security concerns also play a role in limiting the growth.

3. APPLICATIONS OF SMART TEXTILES ON SPORTSWEAR AND WEARABLES

As mentioned before, several smart textiles on sportswear and wearables are already in the market. The following pages reveals some solutions and technology examples:

→ **Nike Adapt BB launched 15 january 2019** [13] (Available: mid-February)

Today: shoe lace tension via App, pressure sensor Contains: a microcontroller, 505 mAh battery, gyroscope, accelerometer, Bluetooth module, motor, lighting, pressure sensor, capacitive touch sensor, temperature sensor and wireless charging coil. All technology packed in the shoe makes it can easily update it to adjust tension itself, count steps, and follow fitness. Similar products: Nike Hyper Adapt (Dec. 2016) and Puma Autodisc (2015).

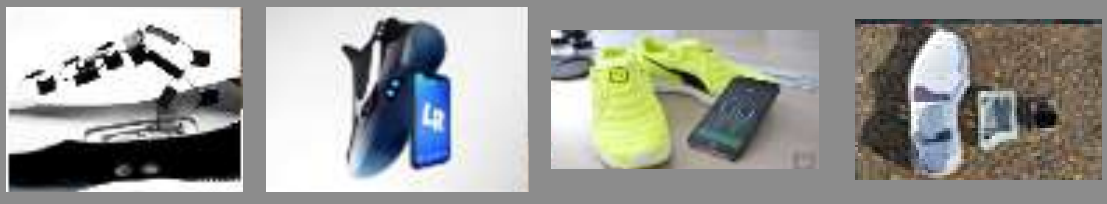

Figure 4- Nike Adapt BB

→ Hövding 3 textile airbag for cyclists[14] (launched in 2011 and updated 2015)

Hövding 3 airbag has accelerometers that detect unusual movement, inflates and forms around the head and neck like a protective hood. Sensors inside the collar read the cyclist's movement pattern 200 times per second. In the event of an accident, the airbag inflates in 0.1 second. It can be connected to smartphone via Bluetooth for access to additional features, such as:

- Selected ICE contacts are automatically notified in the event of a bicycle accident;
- Opportunity for analysis of personal and collective bicycle data
- Battery status with charging reminder.

Figure 5 - Hövding textile airbag

→ CLARA vest for traffic safety[15]

Figure 6 - Clara vest

CLARA vest turn users visible from hundreds of meters and easily spotted from every angle, especially in poor light conditions through the integrated LEDs in the back and the front of the vest. Switch between solid and strobe mode by pressing the button directly placed onto the vest. Through a small and detachable wireless remote placed on the handlebar of the bike, it is possible to activate the turn signals by pressing the right or left button, showing the intention to take other road.

→ Hexoskin[16]

The Montreal-based smart clothing startup recently unveiled its latest connected shirt that's laced with sensors. Along with monitoring heart rate, HRV, breathing rate and minute ventilation, activity intensity, peak acceleration, steps, cadence, positions, and sleep, it is fitted with a Bluetooth Smart sensor so that it could be paired with MapMyRun, RunKeeper and Strava, as well as a whole host of third-party accessories. Data is captured in real time and sends it all to the companion app, providing insights on a range of sporty metrics including intensity and recovery, calories burned, fatigue level and sleep quality.

Figure 7 - Hexoskin

Athos Smart Clothes[17]

Athos makes athletic smart garments, which are fully integrated with wearable technology that tracks heart rate, breathing levels, and monitor muscle activity.[18] This technology is used to monitor athlete workouts and using the data to determine physical readiness to play the game. Men's Compression Shirt and shorts offers real-time biometric tracking, including muscle activity, heart rate, calorie expenditure and active time versus rest time.

Shirt tracks exertion of the major upper-body muscle groups: pecs, biceps, triceps, deltoids, lats and traps.

Made of 76% Nylon / 24% Spandex Lycra, contains 14 seamlessly integrated, non-adhesive biosignal sensors (12 EMG sensors, 2 heart rate sensors).

Shorts tracks exertion of the major lower-body muscle groups: inner quad, outer quad, hamstrings and glutes.

Figure 8 - Athos smart shirt and shorts

Sensoria[18]

Sensoria offers a wide range of smart products (garments, socks and shoes), apps and a platform access, allowing to measure athletes performance. The fitness Smart Sleeveless T-Shirt S tracks heart rate and zones, heart rate variability, pace, speed, distance, calories, and when used with the smart socks it provides advanced metrics for running, such as foot strikes, cadence and more. The Sensoria Fitness Smart Sports Bra provides you with accurate and consistent heart rate monitoring without the hassle of wearing a strap.

Figure 9 - Sensoria smart products (Sleeveless t-shirt, Sports bra, socks and running shoes)

The Sensoria® socks are paired with a Bluetooth Smart cool and detachable Core that not only delivers superior accuracy in step counting, speed, calories, altitude and distance tracking, but goes well beyond that to track cadence, foot landing technique and the impact score generated as you walk and run.

The Sensoria Smart Running Shoes bring plenty of advanced metrics, including foot landing, foot contact, impact, cadence, speed, altitude, descent and some more basic stuff like steps, distance and calories burned. The platform can also be used with an external HRM. As well as improving your running technique and ultimately helping your run faster and longer, Sensoria are aiming to reduce the risk of injury caused by bad form. According to recent research data, 65% of runners get injured every year and the average runner gets injured every 100 hours.[19]

→ SmartSock from Alphafit [20, 21]

A pressure-sensitive Smart-Textile in sock form can be used to determine the fit between foot and shoe. Due to changes in resistance in the textile, it recognizes the pressures acting and can assign them locally. The product SmartSock from Alphafit, for example, is such a Smart-Textile in sock form and allows a 3-dimensional pressure measurement. This allows the forces acting on the foot to be determined. The matrix structure allows a local assignment to be realized, whereby these forces can be reflected on the real foot-shoe system. This allows the fit between shoe and foot to be determined.

Figure 10 - SmartSock from Alphafit to measure fit

Another example in the field of smart textiles for feet are the soles from Moticon, which analyses the weight distribution, the rolling movements and the walking behavior.

→ Wacker Chemie (EAP) Leap Technology [22, 23]

Sportswear with integrated sensors, produced by LEAP Technology (based on ultrathin silicone films and conductive silicone elastomers) that convert mechanical energy into electricity, allow monitor breathing or body movements on a computer screen.

Figure 11 - Wacker Chemie (EAP) Leap Technology

→ Heddoko Smart Clothes, Personal Sports Coach [24]

Figure 12 - Heddoko smart clothes

Heddoko smart clothes track the movements of the wearer with a suit of sensors embedded into the fabric. Heddoko's companion app then processes the data and a 3D model of the wearer is created providing real-time fitness coaching and feedback. The wearer's biometric data is sent to the cloud where it's analysed. As information is shared and compared in the cloud, users can also view the data of professional athletes using Heddoko and learn from their routines to be inspired.

Over time, Hedokko will develop a profile of its user to keep track of progress. It tracks stress levels to your joints and muscle fatigue providing a broad picture of how the user can avoid injury.

→ Antelop suit [25]

The ANTELOPE.SUIT has a total of 16 silicone electrodes integrated into a textile comprised of the ANTELOPE.SHIRT and ANTELOPE.SHORTS. The SHIRT has electrodes located on the abdomen, chest, shoulders, back and upper arms. The major muscle groups, leg biceps, quadriceps and buttocks can be stimulated through the six electrodes integrated into the SHORTS.

All electrodes are supplied with power via the BOOSTER, the energy source of the SUIT. The ANTELOPE.APP serves as the central control unit. In the APP you will find special training programs for strength, endurance and regeneration as well as other important information.

Figure 13 - Antelope suit

Myontec - Mbody shorts[26]

Figure 14 - Mbody shorts

Mbody shorts has 6 EMG channels, complete the lower body circle by adding the glutes data to the existing hamstrings and quadriceps. Features include objective muscle training monitoring, Screening, kinesiologic analysis of movement disorders, gait and posture disturbances evaluation, muscle imbalance detection and technique analysis

Ambiotex[27]

Ambiotex's smart shirt, with the help of the integrated sensors into the garment along with the clip-on box to record the data, measures heart rate variability, anaerobic threshold, as well as fitness and stress levels. Data can be viewed in real time on the companion smartphone app where individual training programs and insights into biometric data are provided.

DynaFeed[28]

DynaFeed is a smart garment that uses advanced biosensor technology and ultra-thin conductive polymer coating to directly measure the voltage potential of a heartbeat. DynaFeed empowers athletes through the body map compression design, optimizing contact for the most accurate heart rate in motion tracking without any barriers or discomfort.

DynaFeed's contemporary design provides high durability that enhances wash cycles and resistance to chemical oxidizers by more than 500%. It permits direct and accurate measurements of vital biometrics data up to 99.7% accuracy by typical ECG methodology. DynaFeed users are also able to pinpoint areas of concern and monitor specific data such as fat burn or cardio zone.

→ Ralph Lauren PoloTech[29]

The PoloTech shirt (made in partnership with OmSignal), through advanced biosensors, tracks activity, stress, physical and physiological condition that helps to get an optimized control of the body during sports training. Metrics include heart rate and variability, breathing depth and recovery, intensity of movement, energy output and stress levels, steps taken and calories burned.

Figure 15 - Ralph Lauren Polo Tech

→ Polar Cardio Sports Bra[30]

The Cardio Sports Bra is a heart rate-sensing sports bra that integrates Polar's sensing technology directly into the bra.

Figure 16 - Polar cardio sports bra

→ Adidas Smart Bra[31]

The Adidas smart bra features high-tech fibre electrodes, which are built into the fabric. It offers support for your back and shoulders during workouts. The connected bra brings accurate heart rate monitoring, even during high-intensity workouts thanks to its dual-layer construction that makes it as tight as a second skin.

→ AIO Sleeve by Komodotec[32]

The sleeve holds a small tracking device that's packed with sensors, a Toshiba processor and internal memory that slips into the smart garment. From here it can collect information on your heart beat, sleep and even deliver data on the intensity of your workout. It uses electrocardiogram (ECG) technology to monitor heart rate activity, detecting the electrical activity produced by a heartbeat. That's all sent in real time to the AIO companion smartphone app.

Figure 17 - AIO Sleeve

→ Moov HR Sweat™[33]

Figure 18 - Moov HR sweantband and swim cap

The Moov HR comes as a sweatband or swim cap. They both offer the same ECG-accurate HRM on dry land or in the pool. When creating their smart headgear, Moov extensively tested multiple body parts to find out where to get the accurate results. The results were that monitoring your heart rate from the head - around the temple area - is the best.

The connected headband can work alone or with the excellent Moov trackers. Together they offer advanced metrics and live audio coaching for running, walking, boxing, cycling, gym workouts, body weight workouts, and HIIT sessions.

→ Myovolt Wearable Vibration kits[34]

The Adidas smart bra features high-tech fibre electrodes, which are built into the fabric. It offers support for your back and shoulders during workouts. The connected bra brings accurate heart rate monitoring, even during high-intensity workouts thanks to its dual-layer construction that makes it as tight as a second skin.

Figure 19 - Myovolt wearable vibration kits

→ Bioman+ AiQ Smart Clothing[35]

Bioman+ is a base upper body garment solution for a wide range of smart clothing solutions. It consists of conductive fiber based textile electrodes for the acquisition of the electric activity of human body as well as conductive thread to carry the electric signals to the processing & transmission module that is snapped onto the garment. Bioman+ has been validated with most of the industry leading heart rate & ECG module vendors.

→ Visionbody's Wireless EMS Suit[36]

The main features of The Visionbody's Wireless EMS Suit are: The Arbitrary Waveform Generation adapts the frequencies gently but dynamically to the body's muscle and nerve processes; Precisely timed muscle stimulation takes the refractory period of the nerves into account.

This means that pulses are sent only when the nerves are receptive; Duty Cycle Variation control the ratio of pulse to time period perfectly; Any physical imbalances such as different performance on the right or left are quickly compensated. In addition to automatic frequency adjustment, the pulses can also be modulated manually between soft, medium and hard depending, on the type of exercise, training goal and fitness level, without assistance and continue with their training.

Figure 20 - Visionbody's wireless EMS suit

→ G4 Mocapsuit SE Sports Edition[37]

The G4 Mocapsuit SE Sports Edition is specifically designed for physical exertion, making it ideal for sports movement analysis. Up to 24 washable micro-sensors can be embedded in the super-flexible second-skin. The system allows for multiple suits to be tracked simultaneously, with zero drift. Flawless motion capture data enables easy comparison of athletic performances. No need to remove sensors when washing.

Figure 21 - G4 Mocapsuit

→ I-Motion EMS[38]

I-motion is a Spanish company that manufactures wireless EMS electro-stimulation equipment.

→ WISE[39]

WISE is composed by a sensorized garment with an incorporated network of electrodes, able to read the electrical signals generated by the muscles. The smart electrodes can acquire the electric potential generated by muscles during their contraction (surface electromyography - sEMG) and the local perspiration level (Galvanic Skin Resistance - GSR).

The signal is digitally converted as soon as it's acquired, granting a professional-level quality. The smart electrodes are embedded in the garments in correspondence with the muscular districts meant to be monitored. The acquired signals are transmitted to the Master via integrated textile wires. Garments can be washed.

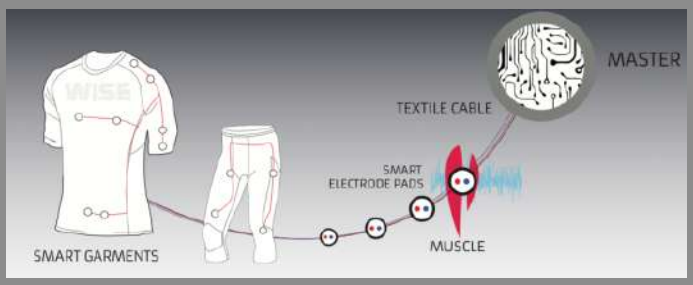

Figure 22 - Wise technology approach

→ Xenoma[40]

Xenoma combines smart apparel with highly developed motion capturing technology, which brings wearable sensors close to various applications in sports, health and industry. The system includes sensor calibration and magnetometer-free motion capturing algorithms and combines it with Xenoma's e-skin smart apparel, which can be used in everyday life. This enables a variety of applications in rehabilitation, sport, work safety and wherever detailed and robust motion capturing is required.

For the first step of collaboration, Xenoma developed a smart pants integrating seven 6-axis IMUs. Furthermore, this solution does not interfere users' movements and is not affected by magnetic environment like machines and facilities, which is important for use cases in industrial environment.

Figure 23 - Xenoma smart apparel

→ exoRehab from Korean startup EXOSYSTEMS[41]

In collaboration with Seoul National University Bundang Hospital and Wonju Severance Christian Hospital, this start-up developed a system integrating motion sensors, EMG and electrostimulation features with a gamified approach to guide the exercises, enhance patients' motivation and compliance, and provide real-time feedback. Data are also remotely available to clinicians on a web portal. exoRehab was presented at MEDICA 2018 and CES 2019 and received approval by the Korean Ministry of Food and Drug Safety (KFDA) and Korea Good Manufacturing Practice (K-GMP).

8K Flexwarm Heated Jacket[42]

he 8K Black Heated Jacket for Men can reach temperatures of up to 50°c (122°f) in just 360 seconds, providing perfect warmth in any weather conditions. Flexwarm® technology can be printed and layered onto fabric. Flexwarm® app allows precise control of 3 unique heating zones.

Figure 24 - 8K Flexwarm heated jacket

Venture Heat Deluxe Heated Jacket Liner[43]

Figure 25 - Venture Heat deluxe heated jacket liner

The main goal of Venture Heat Deluxe Heated jacket liner is to wear it underneath your regular motorcycle jacket or on its own and feel the warmth to your core body while your ride in the cold. This solution is designed to interconnect with other heated gear and plugs right into your motorcycle battery.

Heat sock 5. Toe cap (Lenz Heated Socks)[44]

The heating socks provide up to 14 hours of warmth and have three adjustable heat settings that can be controlled from your smartphone. The lithium packs are easy to attach by means of press studs on the leg band. It can be machine washable at 30 °C.

Figure 26 - Heated sock 5 toe cap

Volt Heated Socks[45]

Volt Heated Socks, with an extra thin heated sock, liner, provides up to 10 hours of soothing warmth to help rejuvenate numb toes and cold, tired feet. Hand Wash.

Figure 27 - Volt heated socks

SeaB2 jacket[46]

The SeaB2 jacket has an integrated inflation system, which is activated automatically as soon as it hits the water.

Figure 28 - SeaB2 jacket

Dainese Smart Jacket[47]

Figure 29 - Dainese smart jacket

The Smart Jacket senses and analyses everything that goes on around the motorbike. It uses its seven sensors to monitor and process data 1,000 times a second. Its complex algorithm enables it to automatically recognize dangerous situations (lowsiders, highsiders, collisions with objects or other vehicles, and rear-end collisions) and activate immediately, whenever it needs to.

IOFIT Smart Golf Shoes[48]

OFIT are designed for casual golfers, pro golfers and golf coaches who are looking to raise their game as well as adding a bit of connected fun to the occasion. Built into the outsoles of the shoes are motion and pressure sensors.

Figure 30 - IOFIT smart golf shoes

They connect via Bluetooth 4.0 to the smartphone or tablet to provide real-time coaching feedback for important aspects of your game. To help maximize your drive and keep steady on the green, the smart shoes analyze asymmetries in balance in your feet between left and right, and front and back. They also monitor ground contact, center of gravity, pressure distribution, time, consistency and more to provide a detailed swing analysis.

HOVRTM[49]

HOVRTM uses Under Armour's Record SensorTM technology to connect to the smartphone app called MapMyRun. The app tracks you through the course of a run and reports details such as pace, cadence, stride length, and distance travelled.

Figure 31 - HOVRTM smart shoe

GoGlove Mobile Gadget Controlling Smart Gloves[50]

Figure 32 - Goglove mobile gadget

GoGlove is a wearable wireless remote control. It uses Bluetooth 4.0 LE, fingertip sensors and a magnet in the thumb to control your smartphone. You can use single or double-tap motions to play, pause, skip forward and backwards through your tracks, control volume, control your camera, GoPro and other apps, it can also activate Siri.

KJUS Men's BT 2.0 Gloves[51]

These Bluetooth gloves let you make phone calls without getting your smartphone out. Thanks to the integrated OLED display, you can even see who is calling.

Figure 33 - Men´s BT 2.0 Gloves

DOUBLE SAFETY WITH ABS® TWINBAGS[52]

The avalanche airbag TwinBag system, ABS® ensure double safety with two completely independent airbags. Both airbags are filled independently with separate valves and hold the air independently - if one valve or airbag is damaged, a second one always remains.

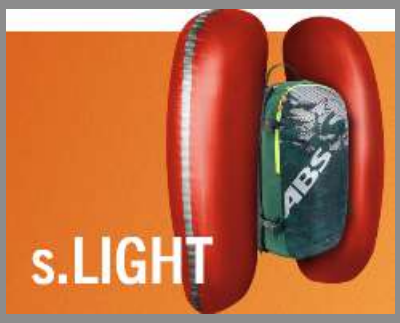

Figure 34 - Double safety with ABS® Twinbags

Lifepack Solar Powered and Anti-Theft Backpack with laptop storage[53]

This backpack includes an anti-theft lock with coil design, solarbank a powerbank with solar charger, integrated USB port for easy charging and Deluxe drop-proof laptop storage

Figure 35 - Lifepack solar powered and anti-theft backpack with laptop storage

4. OPPORTUNITIES AND TRENDS

4. 1 Important technology developments in the following domains:

4. 1. 1 Quality and stability of the systems

- Electronics adapting to textiles (not the other way round);
- Quality of smart textiles;
- Reliable interconnections joining technologies for electronics and textiles;
- Stability of flexible sensors.

4. 1. 2 Towards industry: from what happens in the school (research) to the industry

- Filling the gap between the research prototype and the industrial environment;
- From lab to industry: scale and economy of production;
- From the idea/design to the production (better definition of yarns, structures);
- Simulation of interaction of smart textiles with humans;
- Design and simulation of smart textile antenna;

4. 1. 3 Energy

- Energy harvesting in smart textiles;
- Energy concepts for wearables.

4. 1. 4 Environment and sustainability

- LCA (Life Cycle Analysis) in smart textiles: guidelines for optimization;
- Smart and eco-friendly clothes.

4. 1. 5 Design

- Customization (fit) of sportswear (anthropometrics & movement);
- Freely- confectionable, mass-customizable, sport clothes;
- Integration technologies for durable integration of electronics with good user comfort;
- Mapping of user needs.

4. 1. 6 Specific topics that focus on different technological issues and functionalities

- Micro-/nano- sensors in smart textiles;
- Antibacterial properties in natural fibers;
- Thermoregulation textiles;
- Soft-rigid connections, continual soft-working systems;
- The implementation of location sensors in smart textiles;
- User interfaces: developing relevant scenarios for sports;
- Integration of 3D printing processes in sport smart garments;
- Metallic components on printing materials not allowed in fashion industry;
- Smart textiles: only electronics and software;
- Textile with integrated ECG (biking, medical grade);
- Electrodes for EMS integrated in clothing (forefoot running);
- Cooling capability of sportswear.

4. 1. 7 IoT

Advances in IoT are critical to the success of many wearable products. The small, flexible format of wearable devices means that there is little space available for local data storage components. A possible solution is to store the bulk of data and software applications remotely in the cloud. However, a large number of transactions and data transfer may drain the battery of the system and impact negatively on data security and privacy. This can be counteracted by advances in edge computing to improve the convenience and security of transmitting subject-related data.

Personal calibration of devices and machine learning-based analysis of data tailored for individual data is required for more accurate and relevant monitoring. While big data approaches are available for a specific clinical population, they can be misleading for individual analysis and, therefore, wearable technology should be updated to be aware of “small data” created by individuals and able to accurately interpret minor deviations from large scale control data.

4. 1. 8 Other

- Personalization;
- Legislation;
- Multiple sensors;
- Comfort.

Comfort is defined as an important domain having the potential to make the difference when it comes to smart and functional textiles to wearables (see also the last final remarks).

- Objectives/topics in comfort:
  - Temperature;
  - Color;
  - Energy (production, storage);
  -3D body scanning (fit, individualized production).
- Definition of comfort:[3, 5]
  - Thermophysiological comfort;
  - Skin sensorial comfort;
  - Ergonomic comfort;
  - Physiological comfort;
  - Cooling.

Significant efforts need to be invested into analysing the actual consumer needs and developing products that are market- rather than technology-driven. A clear statement of the benefits of such products then needs to be developed, accompanied by addressing the key consumer concerns and challenges (e.g. safety, environmental and functionality concerns). That should then serve as an input for the large-scale awareness raising and promotion campaigns. Only with a rapid growth of demand, the large-scale manufacturing will become economically feasible and reasonable. In order for Europe to be ready for the demand growth, a cross-regional partnership needs to be established for developing a pilot large-scale manufacturing facility.

4. 2. How to overcome technological bottlenecks

- The possible solutions to overcome the main technological bottlenecks in industrialization and market launch of smart products are:

- The research efforts and the industrialization activities must be better focused in real use cases in order to increase power available to expect successful results;

- The multidisciplinary approach must be strengthened so that more solution proposals will be available in certain application problems. Networks between textiles, electronics, chemists, biologists, physics and end-users, are required, as well as more cooperation between R&D centers and the industry;

- Smart textiles should be understood as a sui generis product and comparison with traditional textiles concerning their performance should be avoided;

- It is important to follow the market trends as they are expressed in specialized exhibitions, special events, etc. and to avoid the design and development of products that are not in the sense of the market needs;

- Definition of marketing strategies focused to support market uptake is required;

- Focusing on critical applications like health, sports, defence, where the price is not the most important factor;

- It is required to assure the reliability of the data generated (data gathering, quality and storage, considering that it should have different levels of confidentiality according to the specific application);

- It is of great importance to connect the smart textile product with the related services like medical supervision in order to increase the added value, as well as to find the niche markets where these services are more valued: handicapped, elderly people, etc.;

- Attention must be paid on the standardization and certification of smart products. Standardization supports the exploitation of the products and it makes the compatibility an important tool for synergies. Scientific certification for wearables is also needed (doctors, authorities);

- A better use of the product development mechanisms is suggested in order to gain the existing experience from the other sectors and similar product categories;

- It is necessary to provide a global offer: integrated solutions concerning to the solution features and maintenance needs;

- It is required to get better textile-electronic interconnections and energy supply technology in order to resist several washing cycles (developing simple tools which can guarantee good connections, deposition techniques that resist washings, low energy consumption, charging batteries wirelessly (induction technology is a very promising technology) and self-powered systems);

- Electronics components are not yet adopted to build a proper and long lasting interconnection with e.g. conductive flexible textile fibers and structures. Suppliers of electronic component need to have a motivation to develop components and micro systems that optimize the connection between soft and hard materials and still resist potential joining and connecting processes.

- The smart textile area has been strongly interconnected with the use of the electronic components, systems and devices in and on the textile products. However, this is not a one-way street, therefore, it is possible to develop smart textile products without electronic components, mainly using other physical, mechanical and chemical principles.

It seems the use of the classical electronic components and devices introduces many problems and mainly instability and low reliability issues.The change of the character from electronics to other principles could lead to a more reliable category of products.

The smart textile area has been strongly interconnected with the use of the electronic components, systems and devices in and on the textile products. However, this is not a one-way street, therefore, it is possible to develop smart textile products without electronic components, mainly using other physical, mechanical and chemical principles. It seems the use of the classical electronic components and devices introduces many problems and mainly instability and low reliability issues. The change of the character from electronics to other principles could lead to a more reliable category of products.

Washing of smart textiles

Smart textiles are quickly penetrating in our life; one of the reasons of not ready for large scale marketing is the difficulty to launder these products. To cope with this issue many smart textile products are made disposable, which eventually cause a higher price of product. The other issue in the washing of smart textile is the lack of standardization, standard EN 15 797 is used for industrial washing of smart textiles and for home washing are (e.g., ISO 6330, ISO BS EN 105 C06, ISO 105-C03, AATCC 61-2A, AATCC 132, AATCC 86).

There are majorly 4 factors responsible for the damage in the washing processes which are thermal effect (temperature), mechanical effect (friction load and bending rigidity), water effect (condensation on devices) and chemical effect (detergents).[54] The products need to be either washed industrially with controlled settings but a smart textile should be able to withstand the home washing as finally they will be laundered by consumers personally. It's important to understand that in washing the product goes through mechanical actions, washing load, rinsing, spinning and drying. Some of these effects can be pre observed by testing the mechanical properties of garment like abrasion testing on Martindale tester, but many of the effects like washing load and wet abrasion bending rigidity are known after washing the product. The temperature range for electronic components used by the general public is limited to 55°C and relative humidity of 40% (non-condensing), which makes it very difficult to have proper washing.

It's still very common to wash the smart textile after removing all the electronics devices whereas the flexible wires or conductive threads are covered with protective sheath to withstand the effect washing and drying. There is overall growth in the research related to washing of smart textile and making it easy for consumer to care.

5. CONCLUSIONS

Final remarks:

- Today there are more wearables in the market (see the examples) than true smart textiles for sports. Trend is that larger companies move away from smart textiles, favoring wearables (like the shoe). Initiatives by SMs, spin-offs, and innovative startups.
- Difficult to compete with e.g. smart watches (According to a recent survey of 2,407 consumers in developed and emerging markets, of wearable technologies, people are least of smart clothing and etextile products).[3]
- Requirements are strongly depending on the type of sports especially weather
- Smart Textiles are used by professional athletes or amateurs.
- An important (emerging) domain, not yet mature, but with strong potential.
- Important issues are:
    - Reliability
    - Washability;
    - Battery/energy;
    - Accuracy sensors;
    - Psychological issues (thermal comfort, tactile comfort, mobility and fashion);
    - Data collected can caused privacy issues ;
    - Textile aspect (not stiff, breathability);
    - Standarization;
    - Potential for industrial production, economy of production;
    - Need for technological progress;
    - Need to use the strength of textiles in this domain, like:
        - Comfort;
        - Multiple sensor application;
        - Larger area for application of sensors brings in unique applications compared to smart watches etc.

Product development driven predominantly by technology push

It's still very common to wash the smart textile after removing all the electronics devices whereas the flexible wires or conductive threads are covered with protective sheath to withstand the effect washing and drying. There is overall growth in the research related to washing of smart textile and making it easy for consumer to care.

Many products only reach the prototype stage

Absence of large-scale manufacturing

In the long-term, the integration into the value chain of traditional large-scale textile manufacturers is crucial, in order to ensure sufficient scale of production.

Value chain players need to be connected

In order to have a complete value chain, there is a need to link multiple regions/clusters together. A pan-European approach towards the value chain is needed instead of a predominantly regional orientation.

The key risks include:

High production costs;

Limited consumer acceptance:

Putting electronics onto textiles needs to be justified by the functionality requirements (e.g. sweat absorption, heart rate monitoring, motion sensing, force monitoring etc.). Otherwise, the benefits for consumers may not sufficient to balance out the costs, and smart textiles will not be able to win it from cheaper and more functional wearable devices/gadgets.

Regulatory gap:

In terms of guidance to companies when it comes to compliance (e.g. testing, assessment, labelling). Some parts of the regulation are already present, but are reported to be highly fragmented; others are still missing and need to be developed. At the same time, stakeholders emphasize that there is no need for more regulatory control. For example, in Asian countries, the regulatory climate is reported to be more flexible. In Europe, there is rather a need for more clarity and systemization.

Hesitance of European manufacturers to invest:

Stakeholders report that limited market demand prevents them from massively investing in the area of smart textiles for sports. A significant growth in demand would make this area attractive to them from a business perspective, and necessary investments could then be justified.

Skills mismatch:

Especially large manufacturing companies often report a considerable lack of skilled people at the level of technicians. There is a need to train multidisciplinary professionals able to combine traditional industries with emerging technological developments; for that, they need to be familiar with both fields and be able to integrate those.

A need to further strengthen a pan-European approach

Towards the development of the value chain (with a key focus on regional level) and ensure a good alignment between EU, national and regional policies.

Communication and how to show the added value to potential consumers, the need for a user driven approach in the designing of the smart textiles and the generation of new business models to drive competitive prices, are very important and urgent issues to address.

Another crucial issue is to solve the problems related with the washing cycles and the textile-electronics' interconnections. To facilitate the market take up of smart products, the market approach should start with a B2B approach prior to deployment to the public as B2C.

One opportunity is to look at higher end segments and providing a hassle free approach for users with strong customer support. In the mid-term, flexible functionality smartness modularity which creates "modules" suitable for production purposes and for repair/maintenance, uptake of 3D printing to obtain flexible structures such as new filaments, and the application of smart textiles in non-invasive personalized measurements is needed. In the long-term, material response based on the user emotions would be a very interesting and innovative area to explore.

Lastly, another important consideration for progress in the short term is the development of new materials such as foams, smart tattoos, bandages or smart bio-textiles. One crucial idea is that the “smartness” of a material is not created by electronics but through other vehicles like biochemistry and bio-organisms such as bacteria. Other untapped opportunities could also be the functionality regeneration during the washing step with specific additives using a key-lock scheme for specificity.

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