

REVIEW OF SMART CLOTHING WITH EMPHASIS ON EDUCATION AND TRAINING

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Abstract. *In recent years, we have witnessed a remarkable development of clothing with increased functionality, such as being able to detect, respond and/or adapt to stimuli from the environment, to which they are exposed, especially in applications for health, recreation, and sports. They allow tracking of athletes during training to improve their performance, health and well-being or contribute to patients' health monitoring, rehabilitation and increase user safety. Today, the development of smart clothing or wearable clothing systems is even more progressive due to the development of smart or intelligent textile materials in collaboration with other sciences. The article gives an overview of smart clothing in the field of sports and health in recent years and highlights the importance of integrating new research achievements into the study process through the extracurricular project education of students in the interdisciplinary field of smart clothing through the last two projects, which were implemented and co-financed by the European Social Fund and the Republic of Slovenia. Such projects promote flexible forms of learning and support high quality career guidance for students at all education levels. The goals of these projects are to solve practical problems in economics using an innovative, problem-based and group interdisciplinary approach to the problem. With this, it is possible to gain practical knowledge and experience. It also promotes innovation, creative thinking, entrepreneurship, and subject-specific skills in the field of study and in other sciences. In addition, the article presents the objectives of the Erasmus+ project OptimTex - Software tools for textile creatives, and the contents of the e-learning module Design and modelling of garments by 3D scanning software and CAD/PDS software developed by the Slovenian partners.*

Keywords: *Smart Clothing; Education and Training; OptimTex Project; E+ Program.*

1. Introduction

Smart clothing usually has smart wearables embedded in it. A smart wearable can be defined as an electronic device worn near, on, or in the body. Smart clothing will be very important in the future for connecting real and digital worlds, replacing or complementing smartphones and other wearable connected devices. Therefore, textile products will become the ultimate wearable medium with flexible electronics for a perfect fit to the body [1].

First wearable computers also contributed to the development of smart clothing. The first in 1955 (and later implemented in 1960-1961) is often attributed to Edward O. Thorp and Claude Shannon. This was a cigarette-pack-sized device worn on the waist to beat Las Vegas casinos at roulette [1-3]. Actual prototypes of smart clothing were not developed soon. Cyberia survival suit, introduced in 2000, was one of the first working prototypes [4]. Its aim was to prevent health incidents by checking the user's physical condition and position in arctic environments. The system was using a receiver (GPS) and various sensors. The sensors (e.g., hydrometer, thermometer) were connected to electrodes embroidered into the textile fabric. First prototypes of intelligent garments were bulky. They also didn't have all features needed for a large-scale commercialization.

Due to improvements in miniaturization of electronics, connectivity, energy efficiency, as well as the ability to embed intelligence in electronic and photonic systems [1], and on the other hand on a huge field of

development of functionalized textiles, smart garments are now remarkably improved. One should mention here also a drastic reduction in the price of components. Smart textiles are textiles that incorporate technologies to detect and respond to the environmental conditions to which they are exposed, allowing the user to experience their enhanced functionality. The sensing of conditions or stimuli can be mechanical, thermal, chemical, or combined [5,6]. The functions may be in the form of (a) an additional electronic component or (b) a part of the textile. Three levels of integration of electronic components and circuits are known: textile-adapted (e.g., mp3 player), textile-integrated (e.g., metal push buttons for optional removal), and textile-based (e.g., using electrically conductive or silver-coated multifilament yarns) [7]. The production of smart or intelligent textiles cooperates with other sciences such as nanotechnology, textile science, design, electronics, computer engineering, etc. Smart or intelligent textiles are also referred to as next generation textiles. In literature, there are many classifications related to smart textiles. One of the classifications divides smart textiles according to aesthetic and performance-related functions (passive, active and ultra-smart textiles) [8].

A smart clothing is a "smart system" that is able to perceive and communicate with the environment and conditions, and stimuli of the user [9,10]. In other words, smart clothes are clothing products made of smart materials or electronic technologies from smart textiles that can perceive, respond to, or adapt behavior to different circumstances [11]. Advanced smart clothes have smart components made of textile materials that ensure comfort. Therefore, the challenge in recent years has been to incorporate electronic functions into smart clothing textiles by maintaining electronic functionality as a specific property of textiles. As additional functions we can mention lighting, sensors, heating and/or stimulation. Furthermore, different internal or external parameters can be recorded. According to McCann et al. [12], smart clothing must be designed from the end user's perspective, taking into account several factors: (a) technical requirements (it must support daily and/or athletic activities; batteries must last long enough to power embedded electronics while monitoring the activity); (b) functionality (smart clothing must be comfortable, i.e., adapt to the human body; embedded electronics must be safe and flexible during body movements and consider the thermal regulation of the human body and possible exposure to body fluids); (c) aesthetics (important for the acceptance of smart clothing) and (d) cultural requirements (user groups and age group; culture, traditions or dress code of the users). Moreover, smart clothing should be washable like normal clothing. Therefore, a combination of wearable technology and clothing/textile science is crucial for the wearability of smart clothing [10,13,14]. In the work of Rotzler et al. [13], a comparison of experts' opinions on the requirements for successful smart textiles shows that washability is the most frequently mentioned criterion and should be considered as very important for a wide acceptance of smart clothing. A brief overview of existing standards for e-textiles is given in the paper by Rotzler et al. [14], which shows that the number of existing standards developed specifically for smart textile products is very small so far and underlines the need for a test procedure for the washability of e-textile systems.

2. Review of Smart Clothing

Human health monitoring can be stated as one of the most important and priority issues today. Therefore, researchers have been working on the development of everyday smart clothing with embedded various types of sensors. Smart clothes monitor wearer's biometric data related to emotional comfort levels and stress. Furthermore, it is possible to monitor vital signs, for example respiration and heart frequency. Smart clothing is able to predict, prevent and monitor chronic diseases remotely, reducing the need for hospitalization and enabling the elderly to remain independent [15]. Smart technologies are included also in different types of sports clothing, such as: T-shirts [16], bras [17], leggings [18], jackets [19], sleeves [20], etc. with the purpose of health and athletes' performance improvement. Due to the abundance of resources, a brief overview of the latest developments in smart clothing for health and sports is provided here.

2.1. Smart clothing for health monitoring

Nowadays, the variety of smart clothing that serve as health monitors like smart shirts [21,22], underwear [23] and even smart socks [50] with embedded cardiac, breathing and activity sensors, can be found on the market. Company Hexoskin has developed a collection of smart shirts with embedded lightweight, machine washable, textile sensors to monitor heart, respiration, and activity [24], Figure 1. Hexoskin connected health platform enables the users to analyse, visualize, and report their data. Smart clothing system primarily developed for personal use, is being used in various studies in the field of human body physiology

and human health [25], elite and professional athletes to optimize their fitness and astronauts to train on space missions [26].



Figure 1 – Smart shirt Hexoskin with embedded cardiac, breathing and activity sensors [27].



Figure 2 – Smart bra for early breast cancer detection [28].

With intent to detect breast cancer Students at Swiss Federal Institute of Technology Lausanne together with the start-up IcosaMed developed the smart bra for detecting breast cancer in early stages, Figure 2, [28]. Advantage of IcosaMed's technology is the emission of ultrasound waves to perform echography scans for potentially cancerous cells [29]. Special piezoelectric pressure sensors generate the ultrasound waves when pressure force is presented. This was used by developers to miniaturize the smart bra's detection system and to assure the required comfort [30].

Continuous health monitoring is beneficial for patients with serious diseases at all stages of life. Individuals with limited ability to change positions, and those who spend most of their time sitting or in bed, have problems with bedsores. To prevent occurrence of bedsores researchers from one of the Slovaks universities developed a smart system for detecting position of a bedridden person with the help of textile pressure sensors [31]. Pressure sensors are attached to the mattress cover and microcontrollers, which are connected to the development board [31], Figure 3. Smart pyjama was developed by company Xenoma with intend to monitor and analyse the wearer's sleep conditions, Figure 4. When paired with a smart home, pyjama automatically adjusts the temperature of the air conditioner and provides proactive exercise tips through the speaker [32].

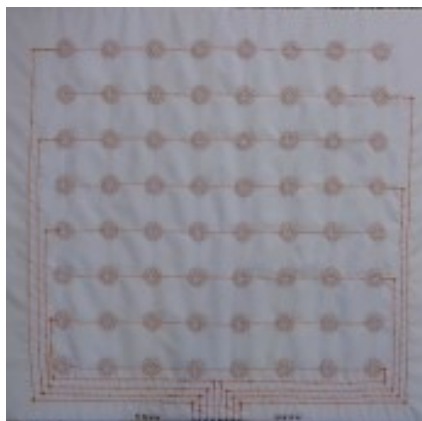


Figure 3 – Bed lining with integrated pressure sensors [31].



Figure 4 – E-skin Sleep & Lounge smart pyjama [32].

Company Xenoma Inc with its e-skin Sleep & Lounge collection became one of five top AiQ smart clothing challengers for 2021 [33]. This year's top three AiQ smart clothing innovators are companies Ease with wearable transcutaneous electrical nerve stimulation product designed for patients with fibromyalgia syndrome [34], Articulare Labs with a neuromuscular electrical stimulation wearable device for

rehabilitation of knees during everyday movement [35] and Thread in Motion with industrial smart glove [36].

2.2. Smart clothing for sports

Paiva et al. [36] developed a smart shirt and leggings for cardiac and muscle activity, temperature, and respiratory rate. Sport set includes cardiac and electromyographic as well as breathing and temperature sensors. Conductive elements (polyamide/silver yarn – Elitex 110/f34 are embedded into shirt and leggings [37].

Textile surface electrodes, embedded into smart sport clothing are used for myoelectric measuring of skeletal muscle potential, using recording technique called electromyography [38]. One of smart systems, using EMG, available on the market is Athos, Figure 5. Athos is a smart clothing system, consisting of both T-shirt and leggings, with ability to measure activity of muscles during workout, heart rate, calorie deficit and time between activity and rest [39]. Athos can be used by both recreative and professional athletes. The Company vision is to expand its application also into clinical environments, i.e. hospitals and rehabilitation institutions. Electromyography- based smart garments can be used by people with different health problems, including heart disease and obesity [40]. Nadi X smart yoga leggings, Figure 6, have integrated sensors and haptic feedback in a form of vibrations. Leggings are special because they can monitor the wearer's movements and provide feedback in the form of small vibrations [41].



Figure 5 – Athos, smart clothing system using electromyography [42].



Figure 6 – Nadi X smart yoga leggings with integrated haptic feedback [43].

Constant health monitoring and high level of protection is very important during work, especially in extreme work conditions. For that purpose, many of smart clothing, that we can find today on market, were first developed for professional, military, and protective use. Special smart clothing with integrated sensors is used by the police, firefighters, astronauts [44-48], etc. Smart personal protective equipment (PPE) is becoming more and more needed. PPE and wearable technologies allow extraction of data related to workers in different environments. This reduces the number of accidents and occupational diseases and leads to a significant improvement in working conditions [49]. A European Agency for Safety and Health at Work has highlighted in a discussion paper the need for smart personal protective equipment and intelligent protection for the future, made a proposal for the classification of types of smart PPE according to composition and data collection capabilities [50]. It also describes the challenges faced by stakeholders, such as the need to establish standards and an appropriate framework for certification and testing. People working outside are exposed to major temperature changes. For this purpose, scientists from the University of Manchester have produced a smart fabric that keeps cool or warm depending on the temperature [51].

3. Development of Smart Clothing - An interdisciplinary cooperation

Today's rapid development of intelligent textiles and garments requires the integration of interdisciplinary knowledge and new research achievements into the study process. Another option is to offer students extracurricular projects that are implemented under the auspices and co-financed by European Social Fund and the Republic of Slovenia, so called 'On the creative path to knowledge'. Such projects promote flexible forms of learning and support high quality career guidance for students at all education levels. The aim of

these projects is to solve practical problems in economics using an innovative, problem-based, and cross-group approach, to gain practical knowledge and experience, and to develop students' innovativeness, creative thinking, entrepreneurial mindset and subject-specific skills.

3.1. Smart clothing for thermal protection of the lower extremities of wheelchair users - SmarTLEGS'bag

Maintaining physical condition is the primary activity of every wheelchair user, which is achieved primarily through daily outdoor activities. The fact is that their integration into the social environment is hindered in windy, humid, and cold weather or even at temperatures that are not a problem for people with reduced mobility. Based on these facts, an interdisciplinary project was created in which a team of eight students from three faculties of the University of Maribor and four higher education, university and master's study programs participated: Textile Design Technologies, Product Design, Mechatronics and General Medicine, under the mentorship of two study areas (Textile Design Technologies, Mechatronics) [52], Figure 7(a).

Recognizing that the thermoregulatory center of paraplegics is disturbed due to spinal cord injury and thus their perception and regulation of lower extremity temperature is disturbed and consequently frequent problems with hypothermia of the lower extremities, lower extremity temperature studies and permitted neural lower extremity temperatures were performed. Through interdisciplinary research and the synergy of knowledge from the fields of medicine, clothing design and manufacturing technologies, functional textiles and mechatronics, smart heating trousers have been developed that bring the skin temperature of a paraplegic closer to that of a healthy individual, which is about 36 °C under clothing. The trousers, called SmarTLEGS'clo, inform the user about the temperature inside the trousers and enable automatic regulation of the temperature in the trousers based on the application for communication between the system and the control system. A communication method via the Bluetooth protocol was used for Android phones, which allows an individual to monitor the outside temperature and the temperature inside both trousers' legs, Figure 7(b). Developed prototype of a smart trousers for thermal protection of the lower extremities of wheelchair users, which offers thermal comfort, protects against weather conditions and at the same time prevents and/or reduces their potential health problems, has been also tested on a thermal mannequin and by a real test person with subjective assessment of the thermal comfort in the air-conditioned room. This additionally gave the students a realistic insight into the developed prototype and the test methods.

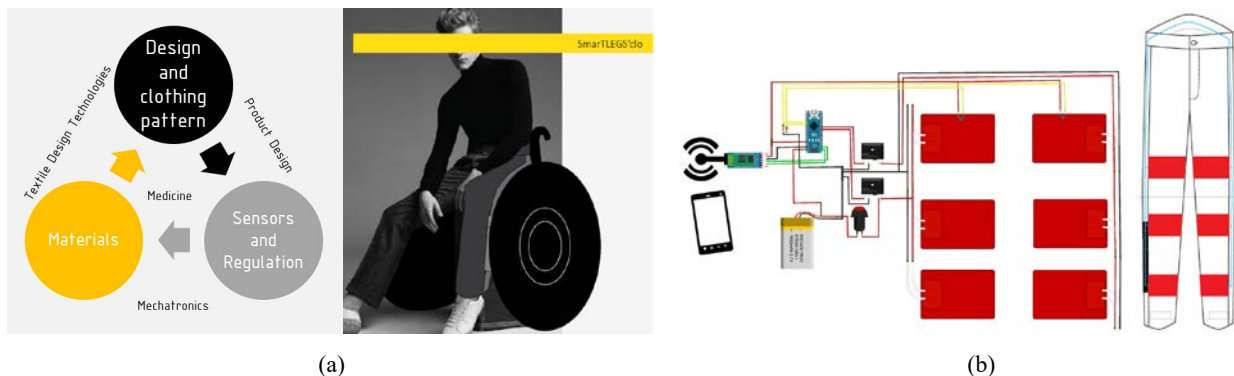


Figure 7 – (a) Interdisciplinary approach to the development of (b) smart pants for thermal protection of the lower extremities of wheelchair users [52].

3.2. Development of a smart sports sock – SmartGo4Goal

The initiative for this project came from the company Go4Goal, d.o.o., which wanted to develop its functional sports socks into smart sports socks that would enable the user (professional or recreational athlete) and (or) the coach to monitor statistics during training and track the progress of professional and non-professional athletes based on targeted training [53]. The project involved an interdisciplinary team of eight students from two faculties of the University of Maribor; the Faculty of Mechanical Engineering and the Faculty of Education, and from the Alma Mater Europaea - ECM from six university, and master's degree programmes; Textile Design Technologies, Product Design, Industrial Engineering - Mechanical Engineering, Mechatronics, Sports Training and Physiotherapy. The development of the smart sports socks began based on one-on-one interviews with recreational and professional athletes about their need for smart

sports socks. This helped students create a questionnaire and initial design of a smart sports sock to order sensors, conductive threads, and other electrical components while studying professional sources.

Then the first prototype of a smart sports sock has been produced. It informs the user about three important foot pressures on the ground, number of steps, distance and speed while running, and calories burned, as well as GPS location based on the Bluetooth communication system application for Android phones. The sock has built-in textile sensors for pressure forces in three locations on the sole and a heart rate sensor in the ankle area. The positions of all the sensors are accurately determined by measurements and calculations of the footprints, the heart rate in the various body parts, and measurements of the characteristic phases of running. The sensors are connected to a unit for receiving, processing, calculating, and transmitting data, which is housed in a small 3D-printed box attached to the sock with conductive presses buttons [53], Figure 8.

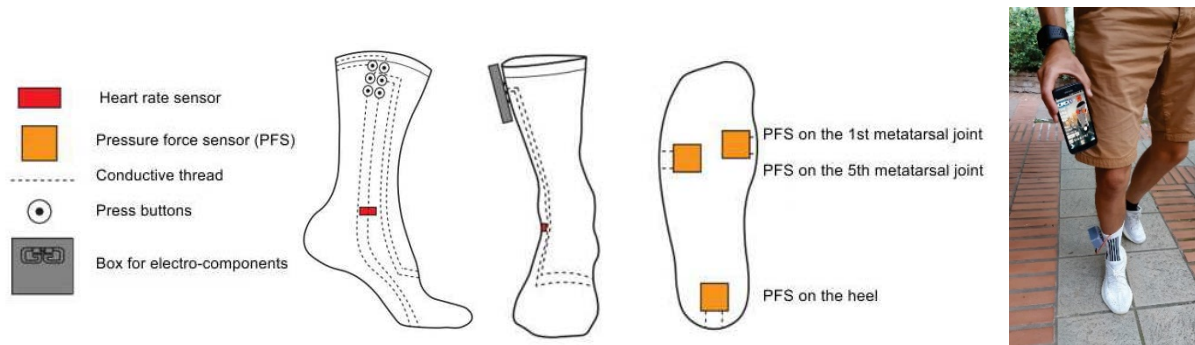


Figure 8 – First prototype of the smart sports sock SmartGo4Goal and an application to monitor the parameters during sports activities [53].

3.3. Erasmus+ project Software tools for textile creatives – OptimTex

OptimTex is a higher education project with an interdisciplinary concept that investigates the links between modern software applications and textiles. The project has three main objectives: (1) course on software applications for textiles, (2): tools for application of software solutions in textile companies, (3) e-learning tool and course organization.

The Slovenian team has developed its module entitled Design and modelling of garments by 3D scanning software and CAD /PDS software. It contains of four examples supported by theory, application and multiple choice questionnaire: (1) 3D scanning of the human body using 3D photogrammetry, (2) 3D modeling and reconstruction of the human body, (3) construction of a 3D kinematic body model, and (4) 3D virtual prototyping of personalized smart garments.

The structure of the module provides the knowledge related to 3D virtual prototyping of personalized clothing using different software tools: 3D Sense, PotPlayer, Meshroom, MeshLab, Blender and OptiTex.

The last example of 3D virtual prototyping shows the development of personalized smart heating trousers for wheelchair users from the point of view of correct positioning of heating elements, temperature sensors and conductive paths for collecting and regulating data in measuring and regulating the microclimate of the trousers to the desired temperature. In addition, the entire process of virtual prototyping and visualization of the clothing is explained and supported by instructional videos.

4. Conclusions

Smart clothing or wearable smart systems provide advanced features to the user. They are able to detect, react and (or) adapt to stimuli from the environment to which they are exposed. Smart clothing has been under development for many years.

The first wearable devices were developed in 1955 and the first smart clothing in 2000. Their development is mainly in the fields of health and sports. With the development of smart textiles and specific applications, they enable health monitoring, medical diagnostics and rehabilitation and increase the safety of users or contribute to improve their performance, health and well-being by tracking and analyzing the training of athletes.

The article provides a brief overview of smart clothing for health and sport, gathered from the wealth of resources available for recent developments.

The second part of the article focuses on the importance of rapid transfer of technology and research advances in the interdisciplinary field of smart clothing to students, through both the learning process and extracurricular education provided by the SmarTLEGS'bag and SmartGo4Goal projects described, as well as the Optimtex Erasmus+ project.

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References

- [1] Fernández-Caramés, T.M. and Fraga-Lamas, P. *Towards The Internet of Smart Clothing: A Review on IoT Wearables and Garments for Creating Intelligent Connected E-Textiles*. Electronics, vol. 7, pp. 405, 2018.
- [2] Thorp, E.O., *The invention of the first wearable computer* in Conference volume: Proceedings of the Second International Symposium on Wearable Computers, 1998, Pittsburgh, PA, USA, 19–20, 1998. pp. 4–8.
- [3] Thorp, E.O., *Beat The Dealer*, 2nd ed. Vintage: New York, NY, USA, 1966.
- [4] Shishoo, R., *Textiles in Sport*, 1st ed. Woodhead Publishing: Sawston/Cambridge, UK, 2005.
- [5] Stoppa, M. and Chiolerio, A., *Wearable Electronics and Smart Textiles: A Critical Review*, Sensors, vol. 14, pp. 11957–11992, 2014.
- [6] Vagott, J. and Parachuru, R., *An Overview of Recent Developments in the Field of Wearable Smart Textiles*, Journal of Textile Science & Engineering, vol. 8, pp. 1–10, 2018.
- [7] Trevisan, B., Bosowski, P., Schaar, A.K., Quadflieg, T., Jakobs, E.M., Jockenhövel, S., Gries, T. and Ziefle, M., *Acceptability studies on smart textiles : an interdisciplinary cooperation to understand users' acceptance* in Conference volume: In Fiber Research for Tomorrow's Applications : The Fiber Society Spring 2012 Conference ; book of abstracts ; Empa, St. Gallen, Switzerland, May 23–25, Seiten/Artikel-Nr: 307–308.
- [8] Canan Çelikel D., *Smart E-Textile Materials* in Advanced Functional Materials, Edited by Nevin Tasaltin, Paul Sunday Nnamchi and Safaa Saud, Published by IntechOpen, November 26th, 2020.
- [9] Tao, X., *Smart technology for textiles and clothing*. Edited by Xiaoming Tao. Woodhead Publishing, 2001.
- [10] Gilsoo, C., Seungsin, L. and Jayoung, C., *Review and Reappraisal of Smart Clothing*, International Journal of Human-Computer Interaction, vol. 25, pp. 582–617, 2009.
- [11] Al Mahmud, A., Wickramarathne, T.I. and Kuys, B., *Effects of smart garments on the well-being of athletes: a scoping review protocol*, BMJ Open, vol. 10, pp. 1–4, 2020.
- [12] McCann, J., Hurford, R. and Martin, A., *A design process for the development of innovative smart clothing that addresses end-user needs from technical, functional, aesthetic and cultural view points* in Conference volume: In Proceedings of the Ninth IEEE International Symposium on Wearable Computers (ISWC'05), Osaka, Japan, 18–21 October 2005.
- [13] Rotzler, S., Kallmayer, C., Dils, C., von Krshiwoblozki, M., Bauer, U. and Schneider-Ramelow, M., *Improving the washability of smart textiles: influence of different washing conditions on textile integrated conductor tracks*. The Journal of the Textile Institute, vol. 111, no. 12, pp. 1766–1777, 2020.
- [14] Rotzler, S., Krshiwoblozki, M. and Schneider-Ramelow, M., *Washability of e-textiles: current testing practices and the need for standardization*, Textile Research Journal, vol. 91, pp. 2401–2417, 2021.
- [15] Brown, D. *The Arrival Of 2020 Brings Smart Clothing To The Forefront Of Healthcare*, YouAreUNLTD.com, □Online□. Available: <https://www.youareunltd.com/2020/01/03/smart-clothing-at-the-forefront-of-a-new-frontier-in-healthcare/> □Accessed October 20, 2021□.
- [16] Ambiotex, □Online□. Available: <https://www.ambiotex.com/> □Accessed October 20, 2021□.
- [17] Werable, *This Supa Powered smart sports bra is a mash up of neon, heart rate and AI*. □Online□. Available: <https://www.wearable.com/sport/supa-powered-smart-sports-bra-features-price-release-date-8888> [Accessed October 20, 2021].
- [18] Indiegogo, *EXISOM: The Most Advanced Set of Smart Clothes*. □Online□. Available: https://www.indiegogo.com/projects/exisom-the-most-advanced-set-of-smart-clothes/coming_soon [Accessed October 20, 2021].
- [19] Margadget, *GAMMA Review: All-Season Graphene Infused Heated Jacket*. □Online□. Available: <https://mrgadget.com.au/gamma-review-all-season-graphene-infused-heated-jacket/> [Accessed October 20, 2021].
- [20] Komodotec . AIO smart sleeve. □Online□. Available: <https://komodotec.com/> Accessed October 20, 2021].
- [21] Cunha, J.P. S., Cunha, B., Sousa Pereira, A., Xavier, W., Ferreira, N. and Meireles L., *Vital - Jacket: A wearable wireless vital signs monitor for patient's mobility in cardiology and sports*. in Conference volume: In Proceedings 4th International ICST Conference Pervasive Computing Technologies for Healthcare, pp. 1–2, 2010.
- [22] The future of things. *Vital jacket will monitor your health*. □Online□. Available: <https://thefutureofthings.com/6389-vital-jacket-will-monitor-your-health/> [Accessed October 20, 2021].
- [23] Mashable. *Of course you can control your smart home with your underwear*. □Online□. Available: <https://mashable.com/article/myant-skiin-smart-underwear> [Accessed October 20, 2021].
- [24] Hexoskin. Health research. □Online□. Available: <https://www.hexoskin.com/pages/health-research> [Accessed October 20, 2021].

- [25] Hexoskin health sensors & AI. Hexoskin white papers. Implementing a remote patient monitoring platform to support home-based pulmonary rehabilitation programs. 2020. □Online□. Available: https://www.hexoskin.com/blogs/news/key-features_respiratorymonitoring Accessed October 20, 2021].
- [26] Hexoskin Atroskin vital signs monitoring platform. □Online□. Available: <https://www.hexoskin.com/pages/astroskin-vital-signs-monitoring-platform-for-advanced-research> [Accessed October 20, 2021].
- [27] Innovate Innovationsoftheworld.com. Hexoskin - Health Sensors & AI. □Online□. Available: <https://innovationsoftheworld.com/hexoskin-health-sensors-ai/> [Accessed October 20, 2021].
- [28] Duotec. Turck Duotec S.A. supports the early detection of breast cancer. □Online□. Available: <https://www.turck-duotec.com/en/news/turck-duotec-s-a-supports-the-early-detection-of-breast-cancer.html> [Accessed October 20, 2021].
- [29] Healthcare in Europe. Smart bra to detect early - stage breast cancer. □Online□. Available: <https://healthcare-in-europe.com/en/news/smart-bra-to-detect-early-stage-breast-cancer.html> [Accessed October 20, 2021].
- [30] EPFLSmart bra for detecting early - stage breast cancer. □Online□. Available: <https://actu.epfl.ch/news/a-smart-bra-for-detecting-early-stage-breast-cancer/> [Accessed October 20, 2021].
- [31] Hudec, R., Matuška, S., Kamencay, P. and Benco, M., *A Smart IoT System for Detecting the Position of a Lying Person Using a Novel Textile Pressure Sensor*, Sensors, vol. 21, pp. 206, 2020.
- [32] Xenoma [dostopno na daljavo]. E- skin Sleep & Lounge. □Online□. Available: <https://xenoma.com/products/eskin-sleep-lounge/> [Accessed October 20, 2021].
- [33] Innovation World Cup Series. The top5 smart clothing start-ups 2020! □Online□. Available: <https://www.innovationworldcup.com/top5smartclothingstartups2020/> [Accessed October 20, 2021].
- [34] Ease. Drug-Free Pain Relief. □Online□. Available: <https://easewearable.com/> [Accessed October 20, 2021].
- [35] Articulate Labs. Kneesteam. □Online□. Available: <https://articulatelabs.tech/> [Accessed October 20, 2021].
- [36] Thread in Motion. Glogi New generation handheld terminal. □Online□. Available: <https://www.threadinmotion.com/products/glogi> [Accessed October 20, 2021].
- [37] Paiva, A., Ferreira, F., Catarino, A. and Carvalho, M., Design of smart garments for sports and rehabilitation. IOP Conference Series: Materials Science and Engineering, vol. 459, pp. 2018.
- [38] Garcia, M.C. and Vieira, T.M.M., *Surface electromyography: Why, when and how to use it*. Rev. Andal. Med. Deport, vol. 4, pp. 17–28, 2011.
- [39] Body hacks. Athos connected apparel next level smart clothes. □Online□. Available: <https://bodyhacks.com/athos-connected-apparel-next-level-smart-clothes/> [Accessed October 20, 2021].
- [40] NPR Will smart clothing amp up your workout? □Online□. Available: Dostopno na svetovnem spletu: < <https://www.npr.org/sections/health-shots/2015/04/03/397108232/will-smart-clothing-amp-up-your-workout?t=1612999314559> [Accessed October 20, 2021].
- [41] Wearable X. The world's smartest yoga pants for men and women. □Online□. Available: <https://www.wearablex.com/collections/nadi-x-smart-yoga-pants> [Accessed October 20, 2021].
- [42] Electric Runway. Athos-smart-clothes-wearable-technology. □Online□. Available: <https://electricrunway.com/awe-wearable-tech-roundup/athos-smart-clothes-wearable-technology/> [Accessed October 20, 2021].
- [43] Trendhunter. Responsive Yoga Leggings □Online□. Available: <https://www.trendhunter.com/trends/smart-yoga-pants> [Accessed October 20, 2021].
- [44] Trotti and Associates Inc. [Online]. Available: <https://trottistudio.com/space/biosuit/> [Accessed October 20, 2021].
- [45] Soukup, R., Blecha, T., Hamacek, A. and Reboun J., *Smart textile-based protective system for firefighters*, in Conference volume: In Proceedings of the 5th Electronics System-integration Technology Conference (ESTC) Helsinki, 1-5, 2014.
- [46] Tectales. Graphene smart textiles developed for heat adaptive clothing [Online]. Available: <https://tectales.com/wearables-sensors/graphene-smart-textiles-developed-for-heat-adaptive-clothing.html> [Accessed October 20, 2021].
- [47] Scataglini S., Andreoni G. and Gallant J., (2019) Smart Clothing Design Issues in Military Applications. In: Ahram T. (eds) Advances in Human Factors in Wearable Technologies and Game Design. AHFE 2018. Advances in Intelligent Systems and Computing, vol 795. Springer, Cham.
- [48] Reiffenrath, M., Hoerr, M., Gries, T. and Jockenhoevel, S., *Smart Protective Clothing for Law Enforcement Personnel*, Material Science. Textile and Clothing Technology, vol. 9, 64-68, 2015.
- [49] Márquez-Sánchez, S., Campero-Jurado, I., Herrera-Santos, J., Rodríguez, S. and Corchado, J.M., *Intelligent Platform Based on Smart PPE for Safety in Workplaces*, Sensors, vol. 21, 4652, 2021.
- [50] European Agency for Safety and Health at Work. Smart personal protective equipment: intelligent protection for the future. [Online]. Available: <https://osha.europa.eu/en/publications/smart-personal-protective-equipment-intelligent-protection-future/view> [Accessed October 20, 2021].
- [51] The University of Manchester. [Online]. Available: <https://www.manchester.ac.uk/discover/news/graphene-smart-textiles-developed-for-heat-adaptive-clothing/> [Accessed October 20, 2021].
- [52] Rudolf, A., Gotlih, K., Marolt, B., Ermenc, H., Štampfer, J., Sadek, Jan, Surla-Pavlović, B., Hudournik, M., Kolanović, V., Novak, J., Borovec, M. and Belšak, R., *Smart heating garment for thermal protection of wheelchair users' lower limbs (SmarTLEGS'bag) (In Slovene)*. Final report: Public tender Project work with the economy and non-economy in the local regional environment - On the creative path to knowledge 2017-2020, Contract number: 11081-24/2018. University of Maribor, Faculty of Mechanical Engineering.
- [53] Rudolf, A. and Gotlih, K., *Development of smart sports socks (SmartGo4Goal) (In Slovene)*. Final report: Public tender Project work with the economy and non-economy in the local regional environment - On the creative path to knowledge 2017-2020, Contract number: 11081-4/2019. University of Maribor, Faculty of Mechanical Engineering.