ClothFace: Battery-Free User Interface Solution Embedded into Clothing and Everyday Surroundings

line 1: 1st Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
line 4: City, Country
line 5: email address or ORCID

line 1: 2nd Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
line 4: City, Country
line 5: email address or ORCID

line 1: 3rd Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
line 4: City, Country
line 5: email address or ORCID

line 1: 4th Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
line 4: City, Country
line 5: email address or ORCID

line 1: 5th Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
line 4: City, Country
line 5: email address or ORCID

line 1: 6th Given Name Surname
line 2: *dept. name of organization (of Affiliation)*
line 3: *name of organization (of Affiliation)*
line 4: City, Country
line 5: email address or ORCID

***Abstract*— This paper introduces ClothFace, a passive ultrahigh frequency (UHF) radio frequency identification (RFID) -based user interface solution, which can be embedded into clothing and into our everyday surroundings. The user interface platform consists of RFID tags, each of which has a unique ID. All the tags are initially readable to an external RFID reader. A specific tag can be switched off by covering it with a hand, which change can then be used as a digital input to any connected device. Because of the used passive UHF RFID technology, there is no need for embedded energy sources, but the interface platform gets all the needed energy from the external RFID reader. In this study, two test setups were created to an office environment: For the Body Test, the interface was integrated into a cotton shirt and into an item. For the Table Test, the interface was integrated into a wooden table. A gameful testing software was created for both setups and two male test subjects tested the platform. The achieved results were very promising: success rates of 99-100 % and 94-98 % were reached in the Body Test and in the Table Test, respectively. Based on these promising preliminary results, we can envision the employment of ClothFace for developing multi-modal interfaces that can provide on-body gestural controls in body-based serious game applications.**

Keywords—gestural control, passive UHF RFID, textile electronics, user interface, wearables.

I. Introduction

Although interaction with technology is an essential part of our everyday life, for many people, different limitations and disabilities are preventing the benefits that versatile digital devices could offer [1]-[3]. For many people, the use of screen-based functionalities is not possible. The available alternatives for screen-based functionalities are usually voice- or body movement-based [4]-[8]. Voice-controlled interfaces have their own challenges, such as linguistic coverage and privacy issues. As an alternative, gesture-based solutions have been suggested [9]-[12]. The current body-movement based solutions have certain limitations, as they either require a line-of-sight to work, an on-board energy source, or they are only useful in a specific configuration.

Passive ultra-high frequency (UHF) radio frequency identification (RFID) is a technology traditionally used for wireless identification and item tracking. This technology consists of battery-free and wirelessly operated tags. The tags draw energy wirelessly from an external RFID reader antenna and respond by sending their unique ID by backscattering. These tags are functional from distances of several meters.

Passive UHF RFID tags can be attached to human body or embedded to the surrounding environment. The backscattered power of an RFID tag changes when a person interacts with the tag, either by touching the tag with finger or by stretching or relocating the tag by body movement [13]-[17]. The change in each RFID tag's backscattered signal power can be monitored. Thus, the changes caused by body movements could then be used for controlling technology [18]-[20]. For the reasons above, the technology has emerged as a cost-effective, battery-free, and multidimensional technology for body movement monitoring and human-technology interaction. The main challenges in these solutions are the noisy and unstable backscattered signals of RFID tags.

In this paper, we present ClothFace, a passive UHF RFID-based user interface solution, which can be integrated into clothing and into our everyday surroundings. The user interface platform consists of RFID tags, each of which has a unique ID. All the tags are initially readable to an external RFID reader. A specific tag can be switched off by covering it with a hand, which change can then be used as a digital input to any connected device. Two different test setups are created to an office environment: For the Body Test, the interface is integrated into a cotton shirt and into an item. For the Table Test, the interface is integrated into a wooden table. Further, a gameful testing software is created for both test setups.

II. Design and Manufacturing of Tags

A. Designs of Body and Item Tags

Firstly, we present the Item Tag, which has a two-part antenna. The antenna design and its dimensions can be seen in

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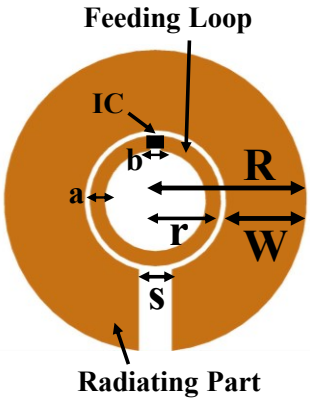
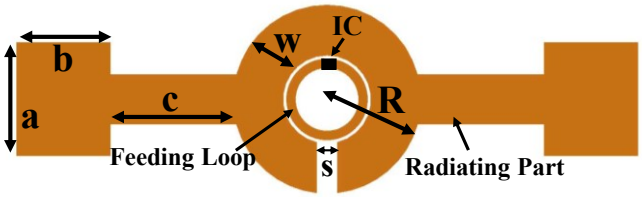
Fig. 1. This type of antenna has been previously presented e.g. in [21]. The first part of the tag antenna is the bigger radiating antenna. The second part is the smaller feeding loop with the RFID IC (integrated circuit) component, holding the unique ID of the tag.



W	R	s	a	b	r
18	30	6.5	3	2	16

Fig. 1. Item Tag antenna design (radiating antenna) with dimensions [mm]. Feeding loop with dimensions [mm] is inside the radiating antenna.

Secondly, we present the Body Tag, which also has a two-part antenna, including the radiating part and the feeding loop part shown in Fig. 2. This antenna has already been successfully tested near the human body in [21]. As this tag antenna has been designed for on-body solutions, it can be used on different body parts.



a	b	c	s	w	R
36	30	39	6.5	16	30

Fig. 2. Body Tag antenna design (radiating antenna) with dimensions [mm]. Feeding loop inside the radiating antenna is like the one in Fig. 1.

B. *Fabrication of Tags*

The Body Tags (radiating antenna and feeding loop) are fabricated from an electro-textile material, which is nickel and copper plated Less EMF Shieldit Super Fabric (Cat. #A1220). Both parts of the antenna are cut from the electro-textile material and then attached to a cotton shirt by ironing over them, as the backside of this material contains hot-melt glue. Both parts of the Item Tag are fabricated from copper tape and fixed on the surface of a wooden table surface and an item (which is a piece of styrofoam). This copper tape has glue on the backside, so the antennas are simply positioned to their places.

The RFID ICs are attached to the feeding loops of both types of tags. This IC belongs to NXP UCODE G2iL RFID microchips (a wake-up power of −18 dBm, 15.8 µW) and it comes with two copper pads (each 3×3 mm^2) fixed on a plastic strap. These copper pads are attached to the copper and electro-textile feeding loop rings with conductive epoxy glue (Circuit Works CW2400). All the ready-made tags can be seen in Figs. 3-5.

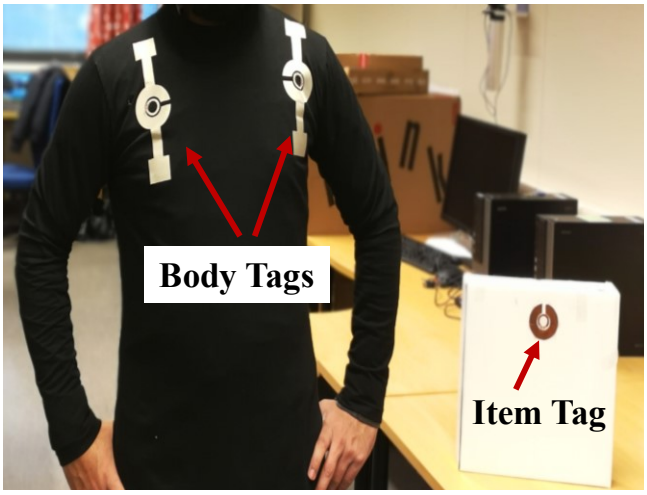


Fig. 3. Ready-made Body Tags (from electro-textile) and Item Tag (from copper tape) integrated into the cotton shirt and into the item on a table.

III. Practical Testing of ClothFace

A. *User Interface Platforms and Testing Setups*

The measurement setup includes Thingmagic Mercury M6 RFID reader, which operates at the European standard frequency range (865.6-867.6) MHz and a circularly polarized RFID reader antenna connected to the M6 reader through a connecting cable. The reader system is connected to a computer through WIFI. The used operating power for the M6 reader in this study is 28 dBm.

The measurement environment, which is a normal office, is challenging for passive UHF RFID tags, due to the many other electrical devices, wireless signals, and human movement inside the office. This testing environment is thus perfect for evaluating the practical usability of the ClothFace user interface platforms.

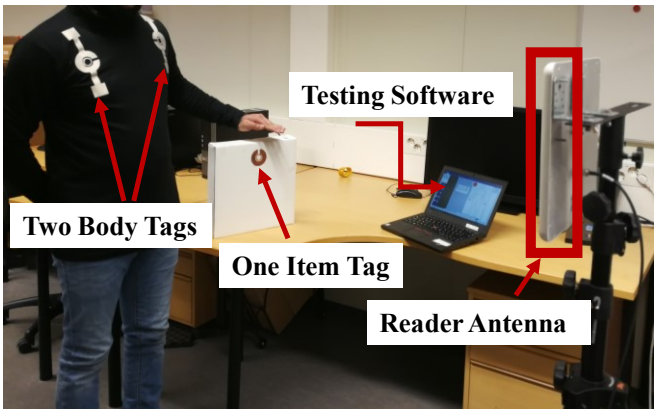


Fig. 4. Test setup for the Body Test: Two Bogy Tags are integrated into the cotton shirt and one Item Tag is attached to the item on a table. Each tag is "selected" by covering it with a hand.

For the Body Test, the interface is integrated into the cotton shirt and into the item on the table. This setup can be seen in Fig. 4 and it includes two Body Tags and one Item Tag. The distance between the interface and the reader antenna is 100 cm. For the Table Test, the interface is integrated into a wooden table. This setup can be seen in Fig. 5 and it includes three Item Tags. The distance between the interface and the reader antenna is 70 cm.

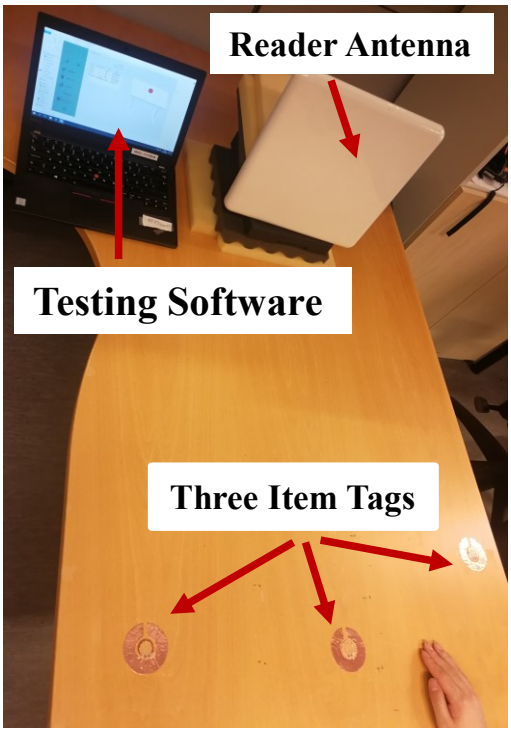


Fig. 5. Test setup for the Table Test: Item Tags 1-3 are integrated into the wooden table. Each tag is "selected" by covering it with a hand.

The used RFID tags are initially readable for the M6 reader. A specific tag can be "switched off" by covering it with a hand, which will then be used as an input to a testing software. A gameful testing software is developed for both test setups. The testing software is developed on .Net framework with C# as windows forms application. It uses ThingMagic Mercury API tools to control the M6 reader and filter received RFID tag IDs to focus only on the ICs on test (and not to be disturbed by any surrounding RFID tags). The ThingMagic Mercury API supports continuous reading, so it is chosen to retrieve RFID tags from the M6 reader.

The developed testing software screens for the Body Test and for the Table Test are shown in Figs. 6 and 7, respectively. Initially, the software shows a random red point on the screen, to which the user must act accordingly, and switch off that specific tag, by covering it with his/her hand. If a correct input is given by the user, a green point appears on the screen, while the software stores the input as "1" in an excel sheet. If a wrong input is given, or there is no input in 5 seconds, the software stored it as "0". The excel sheet contains the information about asked input, given input, and if the given input was correct or incorrect.

ClothFace user interfaces in the Body Test setup and in the Table Test setup are tried by two male subjects. In both test setups, both of the subjects are given 100 random inputs by the testing software.

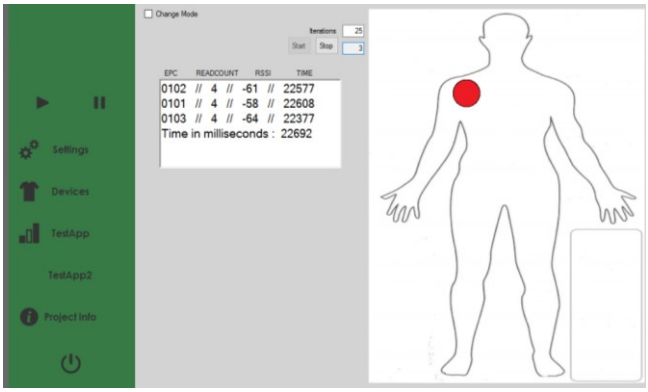


Fig. 6. Testing software screen for the Body Test: The red circle is asking for the Body Tag on the right side to be selected.

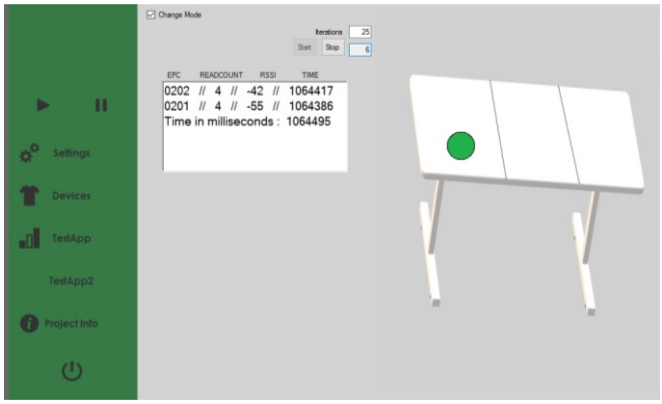


Fig. 7. Testing software screen for the Table Test: The green circle is showing that the Item Tag on the left has been correctly selected.

B. *Measurement and Testing Results*

The backscattered power of a specific tag with a distance "d" between the tag and the reader antenna is given in (1).

$$P_{rx} = P_{tx} {G_{tag}}^2 {G_{reader}}^2 \left(\frac{\lambda}{4\pi d}\right)^4 \alpha |\rho_1 - \rho_2|^2 \quad (1)$$

where P_{tx} is the transmitting power, G_{tag} is the gain of the tag antenna, G_{reader} is the gain of the reader antenna, λ is the wavelength, d is the distance between the reader and the tag antennas, α is the modulation coefficient, ρ_1, ρ_2 are the power wave reflection coefficients of the tag in two different impedance states of the IC.

As indicated in Table 1, the backscattered powers of the tags in the Body Test and in the Table Test are similar for both testers, -53 to -56 dBm for the Body Test and -42 to -49 dBm for the Table Test. The distance between the user interface platform and the reader antenna naturally has a significant impact on the backscattered power.

TABLE I. INITIAL BACKSCATTERED POWERS OF THE TAGS IN THE BODY TEST AND IN THE TABLE TEST SETUPS.

Tester	Body Test			Table Test		
	Body (left)	Body (right)	Item	Left	Middle	Right
U1	-55	-56	-54	-46	-42	-49
U2	-54	-53	-56	-47	-42	-49

TABLE II. SUCCESS RATES OF THE TWO TESTERS IN THE BODY TEST AND IN THE TABLE TEST.

Tester	Body Test	Table Test
U1	99 %	98 %
U2	100 %	94 %

The achieved testing results of the both test subjects from the Body Test setup and the Table Test setup are shown in Table 2. The success rates for the Body Test are very high (99-100 %), but the results from the Table Test are very promising too (94-98 %).

IV. Discussion and Further applications

As a result of this preliminary study, we have successfully integrated ClothFace technology into a wooden table, into a cotton shirt, and into an item on a table. The achieved first testing results are promising and support further development of the solution.

The ClothFace tags can provide various opportunities for contributing to on-body gestural interaction. One of the most important features of ClothFace is that it does not need any on-body energy source, so that users can interact with their clothes in areas where RFID receiver coverage is available. Embedding of those antennas to cloths is relatively easy and low-cost compared to solutions that requires more electronic components to be embedded on the body, such as Jacquard, which uses conductive threads and a Bluetooth transmitter [22] or Botenial, which relies on EMG and capacitive sensing [23]. By combining this technology with previous applications on UHF RFID [17][21], it would be possible to create on-body location sensitive gestural systems capable of distinguishing input methods, such as hovering and touching, which are challenging as reported by previous work [23]. Moreover, it is also possible to detect sequential readings of hidden tags on the body for programming different body-based mid-air gestures (i.e. hovering on three tags from chest to waist can be programmed to decreasing the volume of a sound system).

In this direction, we see many potentials in ClothFace for employing it to many different applications regarding Serious Games and Medical Applications. The versatility of systems that can be developed with the combination of previous [17][21] and the current UHF RFID-based solutions promise the integration of wide array of on-body commands. For example, while most of the systems only can use the body-surface as a touch surface, combination of those systems can provide applications, where hover (mid-air) and touch gestures can be used together. These can provide great opportunities for body-based exergames. As put by game design literature, primary aim of the games is providing fun and pleasurable time [24]. Those qualities are critical for a game to be engaging and immersive. Previous studies on body-based games put forth many guidelines about how to utilize the body for revealing those fun activities. One of the recent works on body-based games indicated that the relationship between körper (the material body) and leib (the experiencing body) should be comprehended thoroughly for the employment of compelling bodily playful experiences [25]. In that sense, ClothFace, even as a novel game control modality, has the potential to uncover playful interactions around the body. Previous work also put forth that the novel utilization of the bodies as game controllers can turn the controlling activity itself into a game [26]. For example, in a game setting, while a hover gesture could activate a specific skill that is effective for certain type of situation, a touch version of the same gesture that can be employed to the same part of the body can activate another skill. The challenge provided by changing between those different kinds of modalities can provide a simple engagement, make users perform required bodily activity, and can also reveal somesthetic interaction qualities [27] by overcoming the interference caused by the problems of tracking technologies.

Other than these, with the introduction of hands-free systems in virtual reality systems, the need for additional controllers can be satisfied by wearables that would incorporate ClothFace system. Employment of such wearables would allow more diversity in terms of body interaction and control modalities in virtual reality systems, which have started to be important platforms for serious games [28][29]. The hovering method of Clothface can also provide advantages in environments, where touching to surfaces or cloths are risky such as intensive care units in hospitals.

V. Conclusions

In this paper, we tested ClothFace, a passive UHF RFID-based user interface platform, which was integrated into a wooden table, into an item on a table, and into a cotton shirt. This technology is battery-free and extremely cost-effective, which makes it appealing for daily use. These first prototypes were fabricated from copper tape and electro-textile materials and both materials proved out to be suitable for this type of use. For the Body Test, the interface was integrated into a cotton shirt and into an item. For the Table Test, the interface was integrated into a wooden table. A gameful testing software was created for both setups and two male test subjects tested the platform. The achieved results were very promising: success rates of 99-100 % and 94-98 % were reached for the Body Test and for the Table Test, respectively. Although these results are preliminary, they provide promising evidence of employing multimodal gestural control, including on-body touch and hover methods that can be advantageous in developing body-based serious game applications in different kinds of media.

References

[1] H. Inoue, H. Nishino, and T. Kagawa, “Foot-controlled interaction assistant based on visual tracking,” IEEE International Conference on Consumer Electronics, Taipei, Taiwan, 2015.

[2] N. W. Moon, P. M. Baker, and K. Goughnour, “Designing wearable technologies for users with disabilities: Accessibility, usability, and connectivity factors,” Journal of Rehabilitation and Assistive Technologies Engineering, vol. 6, pp. 1-12, 2019.

[3] C. L. Fall, A. Campeau-Lecours, C. Gosselin, and B. Gosselin, “Evaluation of a wearable and wireless human-computer interface combining head motion and sEMG for people with upper-body disabilities,” IEEE International New Circuits and Systems Conference, Montreal, Canada, 2018.

[4] C. Harrison, D. Tan, and D. Morris, “Skinput: Appropriating the body as an input surface,” ACM Conference on Human Factors in Computing Systems, Atlanta, USA, 2010.

[5] G. Laput, R. Xiao, X. A. Chen, S. E. Hudson, and C. Harrison, “Skin buttons: Cheap, small, low-powered and clickable fixed-icon laser projectors,” ACM Symposium on User Interface Software and Technology, Honolulu, USA, 2014.

[6] S. Y. Lin, et al., “Pub-Point upon body: Exploring eyes-free interaction and methods on an arm,” ACM Symposium on User Interface Software and Technology, Santa Barbara, USA, 2011.

[7] N. Hamdan, J. R. Blum, F. Heller, R. K. Kosuru, and J. Borchers, “Grabbing at an angle: Menu selection for fabric interfaces,” ACM International Symposium on Wearable Computers, Heidelberg, Germany, 2016.

[8] P. Parzer, A. Sharma, A. Vogl, J. Steimle, A. Olwal, and M. Haller, “SmartSleeve: Real-time sensing of surface and deformation gestures on flexible, tnteractive textiles, using a hybrid gesture detection pipeline,” ACM Symposium on User Interface Software and Technology, Québec, Canada, 2017.

[9] Q. Pu, S. Gupta, S. Gollakota, and S. Patel, “Whole-home gesture recognition using wireless signals,” ACM International Conference on Mobile Computing & Networking, Miami, USA, 2013.

[10] H. Abdelnasser, M. Youssef, and K. A. Harras, “WiGest: A ubiquitous WiFi-based gesture recognition system,” Conference on Computer Communications, Hong Kong, 2015.

[11] W. Wang, A. X. Liu, M. Shahzad, K. Ling, and S. Lu, “Understanding and modeling of WiFi signal based human activity recognition,” International Conference on Mobile Computing and Networking, Paris, France, 2015.

[12] H. Jiang, C. Cai, X. Ma, Y. Yang, and J. Liu, “Smart home based on WiFi sensing: A survey,” IEEE Access, vol. 6, 2018, pp. 13317-13325.

[13] S. Manzari, C. Occhiuzzi, and G. Marrocco, “Feasibility of body-centric systems using passive textile RFID tags,” IEEE Antennas and Propagation Magazine, vol. 54, no. 4, 2012, pp. 49-62.

[14] S. Amendola, L. Bianchi, and G. Marrocco, “Movement detection of human body segments: Passive radio-frequency identification and machine-learning technologies,” IEEE Antennas and Propagation Magazine, vol. 57, no. 3, 2015, pp. 23-37.

[15] H. Ding, L. Shangguan, Z. Yang, J. Han, Z. Zhou, P. Yang, W. Xi, and J. Zhao, “A Platform for free-weight exercise monitoring with passive tags,” IEEE Transactions on Mobile Computing, vol. 16, no. 12, 2017, pp. 3279-3293.

[16] H. He, X. Chen, L. Ukkonen, and J. Virkki, “Clothing-integrated passive RFID strain sensor platform for body movement-based controlling,” IEEE International Conference on RFID Technology and Applications, Pisa, Italy, 2019.

[17] A. Mehmood, V. Vianto, H. He, X. Chen, O. Buruk, L. Ukkonen, and J. Virkki, “Passive UHF RFID-based user interface on a wooden surface,” Progress in Electromagnetics Research Symposium, Xiamen, China, 2019.

[18] H. Ding, et al., “FEMO: A platform for free-weight exercise monitoring with RFIDs,” IEEE Transactions on Mobile Computing, vol. 16, no. 12, 2017, pp. 3279-3293.

[19] R. Krigslund, S. Dosen, P. Popovski, J. Dideriksen, G. F. Pedersen, and D. Farina, “A novel technology for motion capture using passive UHF RFID tags,” IEEE Transactions on Biomedical Engineering, vol. 60, no. 5, 2013, pp. 1453-1457.

[20] W. Ruan, Q. Z. Sheng, L. Yao, T. Gu, M. Ruta, and L. Shangguan, “Device-free indoor localization and tracking through Human-Object Interactions,” IEEE International Symposium on A World of Wireless, Mobile and Multimedia Networks, Coimbra, Portugal, 2016.

[21] A. Mehmood et al., “Clothing-integrated RFID-based interface for human-technology interaction,” Serious Games and Applications for Health, Kyoto, Japan, 2019.

[22] I. Poupyrev, N.W. Gong, S. Fukuhara, M.E.Karagozler, C. Schwesig, and K.E. Robinson, “Project Jacquard: Interactive digital textiles at scale”, CHI Conference on Human Factors in Computing Systems, San Jose, USA, 2016.

[23] D.J. Matthies, S.T. Perrault, B. Urban, and S. Zhao, “Botential: Localizing on-body gestures by measuring electrical signatures on the human skin”, International Conference on Human-Computer Interaction with Mobile Devices and Services, Copenhagen, Denmark, 2015.

[24] J. Schell, The art of game design: A book of enses. CRC press, 2008.

[25] F.F. Mueller, R. Byrne, J. Andres, and R. Patibanda, ”Experiencing the body as play”, CHI Conference on Human Factors in Computing Systems, Montreal, Canada, 2018.

[26] M. Canat, et al., “Sensation: Measuring the effects of a human-to-human social touch based controller on the player experience”, CHI Conference on Human Factors in Computing Systems, San Jose, USA, 2016.

[27] K. Höök, M.P. Jonsson, A. Ståhl, and J. Mercurio, “Somaesthetic appreciation design”, CHI Conference on Human Factors in Computing Systems, San Jose, USA, 2016.

[28] P. Gamito, et al., “Cognitive training on stroke patients via virtual reality-based serious games”, Disability and Rehabilitation., vol. 39, no. 4, 2017, pp. 385-388.

[29] J. Deutsch & S.W. McCoy, “Virtual reality and serious games in neurorehabilitation of children and adults: Prevention, plasticity and participation”, Pediatric Physical Therapy, vol. 29, 2017, pp. S23-S36.