The 25th Edition of the International Symposium on Wearable Computers

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This year marks the 25th edition of ISWC—International Symposium on Wearable Computers—which is the leading research venue for all the topics related to wearables. The conference was held September 21st—24th, 2021, with workshops dedicated to specialized research topics further extending into the 26th. ISWC was co-hosted with the 2021 ACM International Joint Conference on Pervasive and Ubiquitous Computing, as has been the case for a few years.

25TH EDITION

The first ISWC was held at MIT in 1997, and this 25th edition should give us pause to reflect on the advances made in the field and peek into what the future might look like. This 25th edition is also a testimony to the longevity of this area of research, in no small part due to the solid foundations that this community has laid for it over the years. Several dedicated events, including video capturing testimonies of a variety of the members of the community as well as panel discussion) were held to reflect on the achievements of this community. Let us have a look at the salient events from this 25th edition!

ISWC IN NUMBERS

ISWC accepts notes—up to four pages long—and briefs—up to two pages long (excluding references). This year is also the second year that the previous category of "Long" papers (eight pages) are invited to be submitted directly to the journal *IMWUT*, instead of ISWC.

This edition received 102 submissions in total (88 notes, 14 briefs). This is a major increase over the 2020 edition, marked by the onset of the pandemic (70 submissions), and shows a return to the historical average (97 submissions/year on average). This "return to average," even without the long paper category, shows that there is an appetite in the community for submissions of smaller length, which may be more suited to concisely describe novel contributions, and may also be more approachable to the reader.

The submissions were rigorously peer reviewed in a double-blind process, with in the majority of the cases four reviews provided by two external experts and by two members of the program committee. The program committee met virtually on July 17th. During the nine hour-long meeting, the committee worked to ensure a fair evaluation of all papers.

In total, 24 notes and 11 briefs were accepted, originating from Europe (48% of papers), North America (29% of papers), and Asia (23% of papers). Overall, the conference acceptance rate was 34%.

The conference itself was held as a virtual event, with a joint registration to ISWC and Ubicomp totaling 793 participants.

KEY THEMES

This year, the call put a particular emphasis on e-textile and on-skin interfaces, in addition to traditional ISWC topics.

On-skin Interfaces and E-Textiles

ISWC is a leading venue for emerging forms of soft wearable computers, whether in the form of garments

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or emerging forms of on-skin interfaces. For garment-based form factors, Baronetto *et al.* created a simulation tool for evaluating garment-embedded contact sensor performance for different body shapes, activities, and garment designs. This work has applications for more effective sensor placement for applications, such as electrocardiogram (ECG). Bello *et al.* explored a novel body posture and gesture detection garment system via off-the-shelf therein components that does not require sensors to be firmly fixed to the body or integrated into a tight-fitting garment. Instead, sensing can be incorporated into a loose-fitting garment. Moving directly onto the skin surface, Junnarkar *et al.* explored the wearable design opportunities for flexible electrochromic displays that can be worn on the skin for more gradual forms of information representation. In an effort to create more reliable interconnection joints between rigid printed-circuit boards and soft woven-on-skin circuitry for more complicated sensing applications, Huang *et al.* conducted a systematic evaluation leading to design recommendations for such interconnects. ISWC is one of the earliest venues with accepted research in on-skin interfaces. To this end, Lee *et al.* conducted a 10-year review of on-skin interface research in ACM SIGCHI, also charting directions for future directions in this emerging realm.

Wearable Activity and Context Recognition

Activity and context recognition are exciting topics of AI research at ISWC. It is fundamental to enable more natural interaction with wearable devices and it provides the means by which information or assistance can be provided proactively, at just the right time.

One of the challenges of activity recognition is to come up with efficient machine learning models. In the age of deep learning, the work of Bock *et al.* showed that assumptions may need to be revisited, and that in some cases shallower architectures are more effective. Hiremath *et al.* showed that there is a benefit of optimizing separately the length of convolutional feature extractors from the window of data seen by the LSTM layers. Clearly, optimizing these deep learning architectures remains somewhat of an art: the work of Pellatt *et al.* showed a way to automate that process in a tractable, computationally efficient manner through reinforcement learning.

Lago *et al.* showed that it is possible to improve the recognition accuracy of a system, which uses only a minimalistic set of sensors at run-time—when user comfort is paramount—by employing additional sensors solely during training, when users can be more easily instrumented.

Finally, Taghanaki *et al.* showed the benefit of self-supervised learning using pretext tasks for activity recognition.

In addition, Bai *et al.* showed an approach to wearable fatigue assessment using mixed-effect models; Behinaein *et al.* showed how to detect stress from ECG using transformers; Nishino *et al.* showed how to count activity repetitions with weakly supervised learning; and Sanchez Guinea *et al.* showed how activity recognition can be performed with simpler deep models when motion time series data are first converted to images.

Wearable Assistance and Health

Wearables are well suited to providing assistance inconspicuously. Oishi *et al.* explored to which extent wearables could be used to detect a situation encountered by people with Parkinson's called freezing of gait. In order to work around the current lack of wearable datasets, they ingeniously proposed a method to transform motion tracking datasets to the data that would be measured by wearables.

Cardiopulmonary resuscitation is challenging to perform well if untrained. Hermann *et al.* presented a systematic evaluation of where wearable devices should be placed and how their data should be analyzed to most effectively provide real-time feedback on how well chest compressions are administered.

Learning to dance is challenging for many. Villa *et al.* first followed a qualitative research process to understand teacher-to-student motor knowledge transfer. Based on these insights, they then presented a minimum functional wearable device for effective skill transfer.

Kosmyna *et al.* explored an augmented reality headset combined with EEG to detect in real-time covert visuospatial attention, without the need for external stimuli. This may lead to more natural brain–computer interfaces, exploiting the intuitiveness of the natural attraction toward regions of interest in the visual field, for instance for wheelchair navigation.

Wearable Sensing

ISWC has a tradition of exploring how novel sensing modalities can support context recognition.

Alharbi *et al.* presented an own-built thermal sensing wearable with five sensing elements placed on the torso. They demonstrated that it provides sufficient information to distinguish 14 activities when analyzed with a deep network.

Vargas *et al.* showed an open-hardware eight-channel EEG sensing module, compatible with Arduino, a common DIY electronic platform. The authors validated the system using established neuroscience benchmarks, and provided code and design files for reuse by the community.

Synchronizing multiple on-body devices is important for multimodal activity recognition, but is a challenge if a wireless link is to be avoided to minimize power consumption. Wolling *et al.* presented a creative synchronization approach: a signal is transmitted capacitively through the human body, and detected with a repurposed ECG sensor.

While people may wear a smartwatch on their prosthetic arm, that device would not be able to sense their heart rate. Fujii *et al.* showed how to address this by enhancing common smartwatches with an underlying display to stimulate the PPG sensor readings, according to the user's heart rate measured at the junction of the body and prosthetic hand.

Dietary monitoring is often based on chewing sound analysis, which can be captured from a bone-conducting sensor. A first step of that process is chewing cycle segmentation. Kopyto *et al.* revisited that problem with an algorithm derived from beat tracking in music, with promising results on a wide variety of food types.

In addition, Jo *et al.* showed batteryless gait monitoring based on an RDID insole; Röddiger *et al.* evaluated the comfort of a variety of earables for sleep monitoring; Okamoto *et al.* showed how to estimate surface electromyography on the upper arm from photoplethysmography at the wrist; and Isobe *et al.* showed an approach to person identification with active acoustic sensing suitable for inclusion in smart glasses.

Perception and Interaction

Wearable devices are well placed to manipulate subjective perception throughout everyday life, which opens up numerous avenues for innovative applications.

Futami *et al.* showed how presenting biased myoelectric information—which relays how much muscles contract—to users can be used to unconsciously affect their load perception. They evaluated this in a variety of weight-lifting scenarios. This might be used to design novel physical training routines to enhance performance.

Shirai *et al.* instead looked at manipulating subjective time through tactile stimuli provided by a device worn on the wrist, such as a smartwatch. This may be interesting to subjectively reduce waiting times. They showed that subjective time can be modified by up to 20%.

Zhang *et al.* presented smartglasses capable of blocking peripheral vision to address motion sickness, by including a switchable polymer dispersed liquid crystal film, which they positively evaluated in a virtual reality environment.

Pescara *et al.* explored how a wristband can provide directional information through vibration using an absolute or wrist-centered frame of reference. Their results show faster reaction time with the absolute frame of reference even when including different rest orientations of the wrist, which was unexpected. This may be valuable in designing future tactile interfaces.

Finally, psychomotor vigilance tasks are often conducted on mobile devices. Arthurs *et al.* noticed that the latency introduced by mobile operating systems prevents comparing reaction test times against gold standards. They show how to quantify this using an "artificial finger" tapping a mobile phone screen to quantify this latency in a variety of conditions.

In addition, Vekemans *et al.* showed whether emotions can be perceived when presented on a wrist-worn tactile display.

In addition, Tu *et al.* characterized the text entry rate of the Tap Strape chording keyboard; and Huisman *et al.* explored the haptic feedback of head gestures haptically to convey social cues in online conversations.

PANEL ON THE 25TH ISWC: PAST, PRESENT, AND FUTURE

Two panel discussions were held on the topic of *"Past, Present, and Future"* of wearables.

The panelists included 10 researchers whose involvement with ISWC span across its 25-year history (see Figure 1). Chief among these was conference co-founder and steering committee chair, Thad Starner, who was presented with a special award in recognition of his outstanding contribution to the community. The two sessions included lively discussions on the wearables that are now mainstream (e.g., smartwatches, fitness trackers), things that have not quite taken hold (e.g., smart textiles, easy access to our own data), and what panelists believe is still to come (e.g., social wearables, battery-free sensors and actuators, dynamic aesthetics in clothing). For more on 25 years of ISWC, take a look at the recent *IEEE Pervasive Computing* article by some of the panelists.[4]

BEST PAPER AWARDS

The 2021 ISWC Awards were given to one best note, with two notes receiving honorable mentions, and one best brief. The ISWC Awards Committee evaluated the top 10 notes rated by average score from the 24

FIGURE 1. Twenty-five years of ISWC panel and their first ISWC (clockwise from top left): conference co-founder Thad Starner (pictured in 1995), Jen Healey (first ISWC 1997), Kai Kunze (2007), Kristof van Laerhoven (2000), Lucy E Dunne (2002), Tom Martin (1998), Paul Lukowicz (2000), Jamie A Ward (2001), Jingyuan Cheng (2007), and Melody Jackson (2013).

accepted ones, and the top five from the 11 briefs. The published papers and the video presentations were provided to the committee for analysis and discussion.

The best note was awarded to "*Improving Deep Learning for HAR with Shallow LSTMs*" by Bock *et al.*[2] It takes one of the most popular deep learning architectures used for wearables research, and validates that one instead of a two-layered LSTM could be used for sensor-based activity recognition (see Figure 2). We recognized the contribution of challenging the status quo, with results that even increased the recognition performance. This article is also a great example of replicability due to the comprehensive GitHub.

The honorable mentions go to the note "*Assisting Motor Skill Transfer for Dance Students Using Wearable Feedback*" by Villa *et al.* It provided a comprehensive human-centered design process for creating wearables that was exemplified by garments in teaching dance;[5] (see Figure 3a) and the note "*Simulation of Garment-Embedded Contact Sensor Performance under Motion Dynamics*" by Baronetto *et al.* presented a novel method for simulations to evaluate the

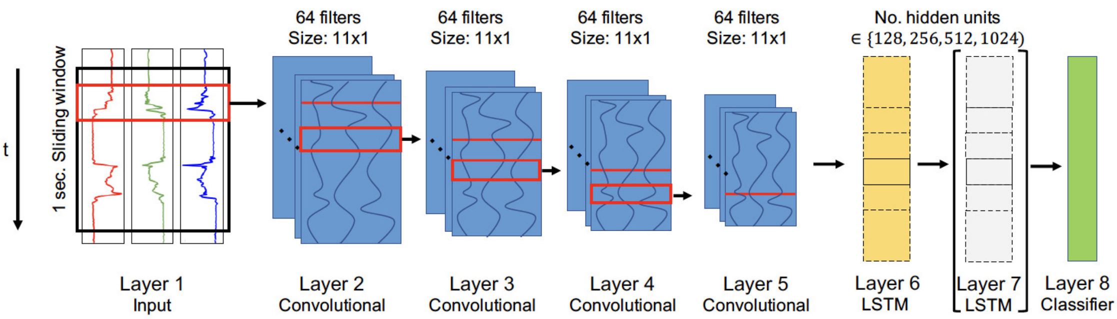

FIGURE 2. Best note award to Bock *et al.* removing the second LSTM layer (layer 7) from DeepConvLSTM.

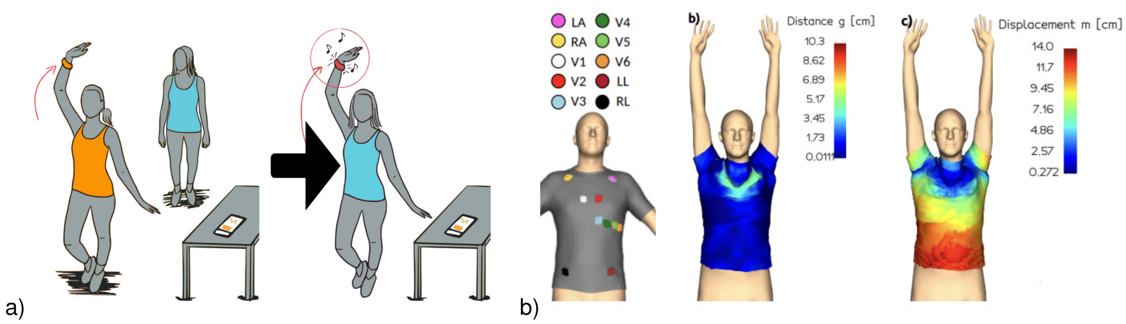

FIGURE 3. ISWC 2021 honorable mentions notes. (a) Wearable systems for motor skill learning by Villa *et al.* (b) Modeling and simulation method to estimate contact sensor performance by Baronetto *et al.*

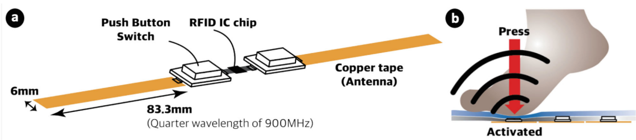

FIGURE 4. Best ISWC brief to Jo *et al.* design of the smart insole with integrated RFID.

performance of garment-embedded contact sensors using the factors of body shape, garment fit and movement type in daily activities (see Figure 3b).[1]

And finally, ISWC 2021 awarded the best brief to "*RFInsole: Batteryless Gait-Monitoring Smart Insole Based on Passive RFID Tags*" by Jo *et al.* due to its novelty contribution with a soft, thin, and batteryless interface that tracks foot pressures by taking a novel approach by incorporating RFIDs directly into a shoe (see Figure 4).[3]

GADGET SHOW

The Gadget Show presented the new wearable gadgets commercial or brewing, in the labs. It was held virtually at Gather Town by Wayne Piekarski, Tom Martin, and Shuyi Sun, who introduced the history of this ISWC event and supported the participants to line up to present their gadgets. A total of 15 participants showcased their prototypes.

Some of the products that were presented include: an industrial prototype of a novel tiny Arduino-compatible microcontroller and sensor board by Bosch; a guitar that has the movability of a Roomba; an on-skin electromagnetic drag, tap, and vibration actuator for wearables; an interactive coloring wig; and a smart sleeve to measure human body shape, which was lauded as "the most complex soldering project ever" by the Gadget Show chairs (see Figure 5, right).

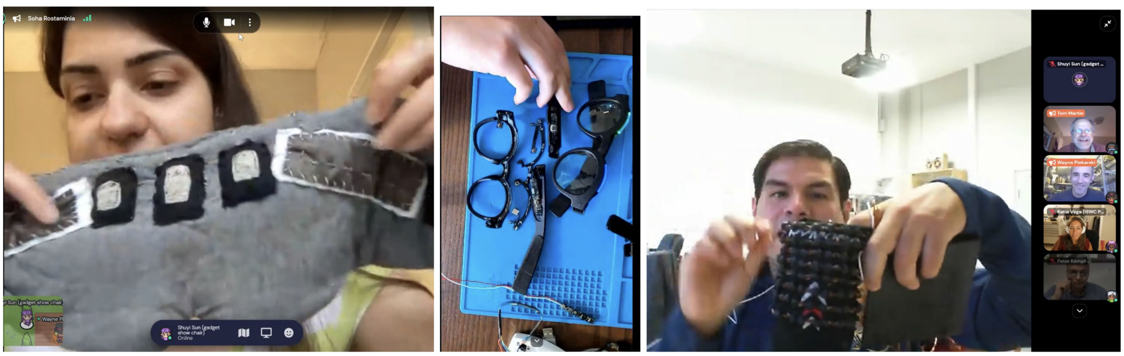

FIGURE 5. Participants to the Gadget Show showcased their prototypes: Roha Rastamina (left), Patrick Chwalek (center), and Leonardo García García (right).

DESIGN EXHIBITION

Since 2009, ISWC has held a Design Exhibition where design practitioners, design researchers, and others engaged in a designerly process open that process up so that others can learn from the practice of creating and wearing a wearable computer. As a note, 2020's ISWC Design Exhibition was transformed into a panel due to the COVID-19 pandemic, we were very happy to see it return as an exhibition this year.

The design exhibition has grown over time from a small event to a full track, with authors submitting a six-page paper, video, and poster detailing the design at a functional and aesthetic level.

It is in each author's profound look into the design process that new knowledge is formed by addressing the technology and the aesthetics of an actually worn thing. Ideas of nomadic practice[6] where the designer confronts specific design considerations has led to a corpus of wearable design literature expressing a richness that Krogh and Koeskien describe as "drifting."

The 2021 design exhibition, although virtual, continued in adding to the richness of wearables design in technique, aesthetics, and functionality. This year, we received 20 submissions of which 12 were exhibited after a double-blind peer review of the paper, video, and poster. The 12 papers were then juried by a group of past ISWC Design Exhibition chairs who chose winners in three categories of functional, aesthetic, and textile arts.

VIDEO TESTIMONIES OF ISWC

A video with testimonies of a variety of experiences with ISWC, from the first general chair to newcomers to this community, was put together to mark this 25th edition. Have a watch at https://iswc.net/iswc21/program/iswc-25th-anniversary.

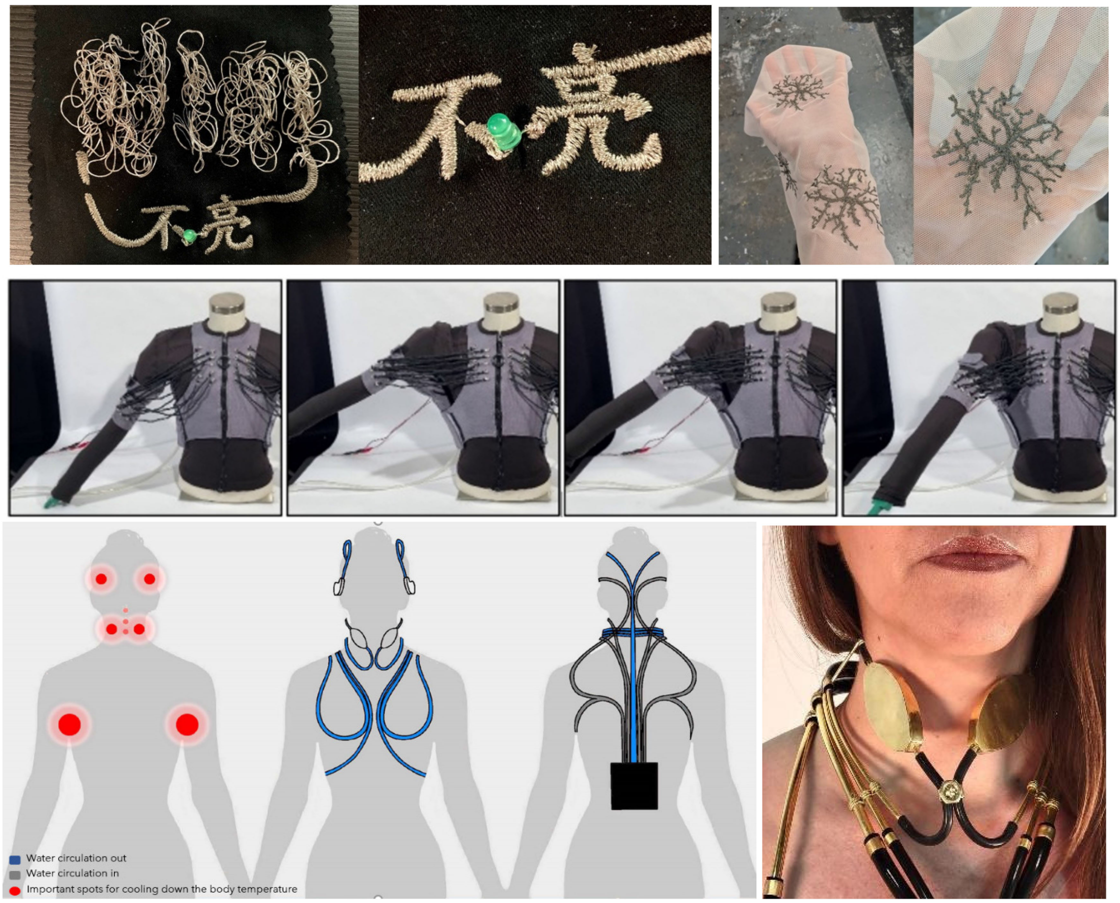

FIGURE 6. Design Exhibition Awards for the best design have been given in three categories: fiber art, and functional, and aesthetic. (a) Sensing textures.[7] (b) Design of a Hybrid SMA-Pneumatic based Wearable Upper Limb Exoskeleton.[8] (c) CJ-2050: Body Cooling Wearable Technology.[9]

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