Making Sensors, Making Sense, Making Stimuli: The State of the Art in Wearables Research from ISWC 2019

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The International Symposium on Wearable Computers (ISWC) has been the leading research venue for wearable technology research since 1997. This year, the 23rd ISWC was held in London, UK from Sept 9-13th. Following on the last 8 years of successful collaboration, ISWC was co-located with the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp).

ISWC by the Numbers
The program committee reviewed 125 complete submissions. The papers had authors from 25 countries, with a balanced representation from the Americas, Asia/Oceania, and Europe. ISWC accepts papers in three lengths: long papers, notes, and briefs. From the 81 long paper submissions, the program committee accepted 21, an acceptance rate of 21%. In addition, 13 papers were accepted as notes and 8 were accepted as briefs. The acceptance rate across all ISWC publication formats was 30%.

Over 730 people attended the co-located conferences. The technical program committee chairs from both conferences prepared a blended program that grouped papers by topic rather than by conference. In addition to oral presentations of papers, the program also included 64 posters and 30 demos, the ISWC Gadget Show, and the ISWC Design Exhibition, a juried selection of creative practice in wearable technology.

The full program was exciting and introduced many new ideas. Papers of all lengths can be retrieved here: https://dlnext.acm.org/doi/10.1145/3341163, and the adjunct program (including workshops, posters, demos, and the design exhibition) is available here: https://dlnext.acm.org/doi/proceedings/10.1145/3341162. Because it's not possible to fully acknowledge all of the content covered, here are some themes and highlights from this year's program.

Wearable Haptics and On-Body Mechanics
Body-worn devices offer a unique platform for haptic actuation, and ISWC authors explored this domain from several angles. The idea of implementing passive haptic learning (learning to do a

motor task like typing or playing the piano by feeling tactile stimuli on your body with or without active practice of the activity) has been a constant theme at ISWC for more than a decade. At this year's conference, Pescara et al. [1] sparked a debate about the relative contributions of active learning and passive haptics in such studies, through a test of learning Morse code. Best Paper nominees Luzhnica and Veas investigated learning of letters and words represented by tactile impulses [2].

Another emerging topic was the use of on-body mechanics to create novel stimuli. Shirota et al. developed a method of manipulating the outer part of the ear in order to change the perceived direction of sound [3]. Foo et al. used shape-memory actuators to squeeze the torso and arms in order to create the sensation of dynamic compression [4].

Haptics and Sensing: (left to right) ear manipulation to change sound direction perception [3], shape-memory actuators for dynamic compression [4], and cardio-respiratory sensor system [5]. Photos © the authors.

Social Dynamics

Wearables in social situations generated interesting research questions at this year's conference. Researchers investigated the use of wearable technology to measure or respond to social experiences as well as the social perceptions of observers viewing others interacting with on-body technologies. Gupta et al. used sensors embedded in smart eyewear to detect eye blinks and head nods and to calculate the degree of synchrony in these behaviors between two conversing individuals [6]. Best Paper nominee You et al. considered 3rd-party perspectives on users interacting with a skin-mounted touch sensor tattoo in various body locations [7]. Finally, Schmidt et al. conducted a broad review of studies that aim to detect affect (emotion or mood) in the wild using body-worn sensors [8]. Their analysis highlights many of the fundamental challenges of doing physiologically-based affect sensing.

E-Textiles

Textile-integrated electronics is a research theme that has been well-represented at ISWC since the first conference. This year was no exception, with papers characterizing the breadth and significance of deployable e-textile toolkits, work on the development of textile-based sensing and circuitry, and unique applications like enabling kinetic garments through e-textile components. Hayashi et al. developed kinetic "smart hairs" composed of shape memory alloys and superelastic alloys and implemented them in a multi-layer, e-textile structure that allows the

individual hairs to be inserted in a plug-and-play fashion [9]. Both Dupler et al. and Golgouneh et al. worked with stitched textile strain sensors. Dupler's analysis focused on characterizing the performance of different strain-sensitive stitches under different loading conditions, while Golgouneh applied a similar sensor to the problem of sensing ankle swelling [10]. Other authors looked at both e-textiles toolkits (and what they reflect about community values and structures) and commercial e-textile products (e.g., reverse-engineering the Google/Levi's Jaquard jacket to enable novel interactions [11]).

Wearable Sensing

On-body sensing (and the sensor hardware that enables sensing) is at the heart of wearable technology research, and this year's conference showcased a wide variety of approaches and application domains. Two papers focused their sensing on and around the heart. Best Paper winners Yoshida et al. introduced a unique new way to resolve the challenge of not knowing exactly where on the body a sensor may have been placed [12]. Using the fact that electricity moves faster than blood flow, they estimate location by measuring the difference in time between an electrocardiogram-sensed heartbeat and the corresponding pulse-wave detected at the sensor location. Zhou et al. took a different approach to measuring cardio (and respiratory) signals by developing a miniaturized system, consisting of an air-pressure face mask and an earlobe-worn pulse-oximeter, that is significantly less bulky than existing approaches [5]. Finally, Yildirim et al. explored a new way to augment human sensing capabilities by incorporating ambient electric field sensing into a vest that then relays these signals to the wearer via electrical nerve stimulation [13]. On-body sensing for animals has also been an emerging topic at the conference, and this year one paper explored the design of on-body biotelemetry for canines [14].

Activity and Gesture Recognition

Methods and applications for detecting human activities and gestures from body-worn sensors remain two of the most popular topics at ISWC (indeed, ISWC was the venue where research of this nature was pioneered). This year's program included ways of recognizing typical activities and movements for use in health, sports, music and sleep monitoring applications. The program also included new work that explored ways of robustly detecting interaction gestures using multiple wearable devices, or by fusing different sensing modalities.

Many papers addressed subtleties of accurate, robust recognition using novel algorithms or analyses. Some examples include Haresamudram et al., who revisited the role of feature representation in activity recognition [15]. The authors compared traditional, heuristic-based feature extraction with recent representation learning methods, concluding that optimized feature learning is preferable to end-to-end deep learning. Du et al. evaluated cascade learning, an adaptive approach to transfer learning, as a low-cost way to do deep-learning on activity data [16].

Other applications explored by ISWC authors included predicting thermal comfort using body temperature and physiological signals, measuring cognitive effort using EMG signal features, monitoring of sleep apnea using a multi-sensor adhesive patch, recognition of swimming styles,

and sensing leg muscle contractions in rehabilitation using a novel ultrasonic sensor. Several papers combined sensing modalities to leverage richer contextual information in recognizing activities. For example, Wang et al, combined muscle activity and wearable motion capture signals to detect pain-protective behavior in sufferers of chronic pain [17]. Perhaps the most unique application represented at the conference was the detection of "fast and powerful down picking of heavy metal guitar" using a wrist-worn inertial sensing device.

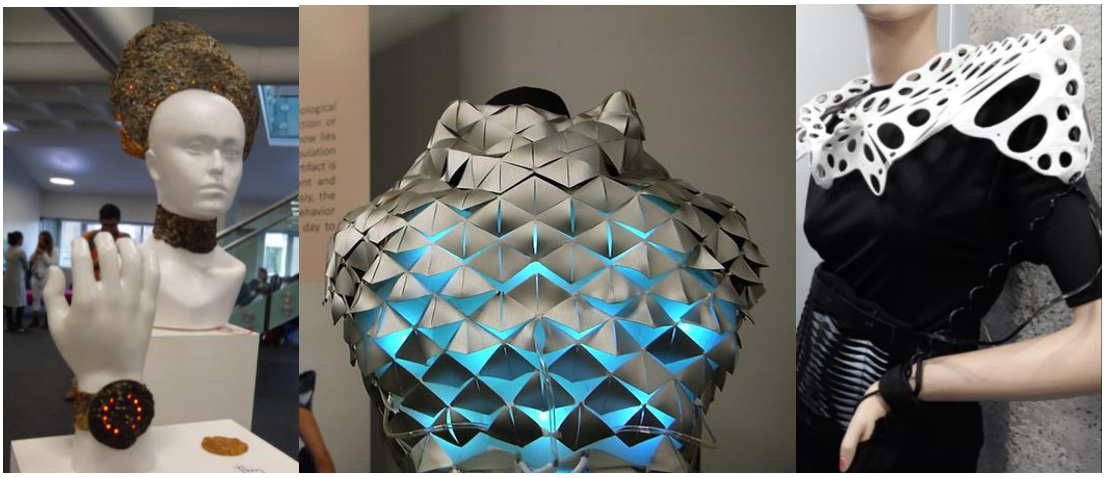
Design Exhibition

2019 marked the 12th ISWC Design Exhibition. Sixteen pieces in three categories were selected for the exhibit by the jury: Functional designs, which emphasize utility and usability; Fiber Art designs, which emphasize textile development; and Aesthetic designs, which emphasize concept and visual impact. One piece in each category was selected for a Jury Award.

In the Functional category, the winning design was *AWE Goosebumps* by Neidlinger et al. (SENSOREE, USA and University of Twente, NL). This piece uses embedded pneumatic actuators to induce a feeling of "awe" through simulated goosebumps. The actuation effect is enhanced through an illuminated display that becomes more visible as slits in the garment's outer covering open when the goosebumps inflate.

In the Fiber Arts category, *Myco-Accessories* by Lazaro et al. (UC Davis, USA) received the Jury Award. The work explores development of biodegradable e-textiles based on the grown material mycelium.

In the Aesthetic category, Wei et al. (IAAC and Datable Studio, Spain) received the Jury Award for *Touch Mood*. This 3D-printed piece uses affective information from the wearer (galvanic skin response and thermal information) to generate a kinetic response using LEDs and a shape-memory driven fabric array.



Design exhibition winners: (left to right) AWE Goosebumps, Myco-accessories and Touch Mood. All photos © Rain Ashford (https://rainycatz.wordpress.com).

Join us for ISWC 2020

The next ISWC will be held in Cancun, Mexico in September 12-16th, 2020 (http://iswc.net/iswc20). The paper submission deadline will be announced in early 2020. For updates, subscribe to our Twitter feed @ISWCNET.

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