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Hardware is Hard—is it Worth it?

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ABSTRACT

Within the field of technical human-computer interaction (HCI), there is a community of researchers who innovate in hardware: they build new device form factors, experiment with sensing, actuation and displays, and they deploy and study novel devices. Their work underpins many new and inclusive user experiences. A common perspective is that developing hardware is hard, especially in comparison to purely software-based activities. It typically involves a multitude of disciplines in addition to software, likely relies on third parties such as parts suppliers and manufacturing partners, has inherent delays that stifle agility, and it costs more. Is hardware really 'harder' though? And if it is, is innovation in hardware a worthwhile endeavor for the HCI community? This panel will discuss these topics with the aim of giving attendees a deeper understanding of the difficulties and benefits of hardware research in an HCI context.

CCS CONCEPTS

• **Computer systems organization** → *Embedded systems*; • **Hardware** → *Design for manufacturability*; • **Applied computing** → *Industry and manufacturing*.

KEYWORDS

Hardware research, device innovation, ubiquitous computing, interactive devices, IoT

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1 INTRODUCTION AND AIMS

Whether it is intentional user interaction, context and environmental sensing, or situated information displays, we are dependent on interactive hardware to provide the vital connection between our ever-expanding networked computer systems and the real world [8]. Indeed, as the "internet of things" computing paradigm becomes established, we see continued growth in both the number and the type of these interactive devices. But it's not clear exactly what form these devices will take, or indeed how many different forms are needed [9]. Therefore, the ability of the HCI research community to design, build and evaluate devices with new functionalities and new form factors would seem to be of key importance. By doing this we can, for example, target emerging application areas, new contexts of use and more diverse populations—all with the ultimate aim of unlocking improved capabilities and experiences for users.

The development of new interactive hardware devices can be split into two phases [16]. The first phase is a period of ideation, prototyping and design iteration that leads to new device concepts. Hardware researchers in the HCI community often excel at this! Indeed, many of us have even created systems and platforms to aid other researchers in their prototyping endeavors—reducing the time, money and/or level of expertise needed [1, 3, 4, 6, 10, 14, 17, 19, 20, 25]. In short, building prototypes has arguably become democratized [11].

Following initial prototyping, the second phase of hardware development identified in [16] involves scaling—creating copies of the prototype. Initially there may be a requirement for tens or hundreds of devices for further evaluation, and pending success with these a process that supports on-going production may ultimately be warranted. Evidence shows that this second phase of "delivery", and in particular the reliable replication that underpins it, is often unexpectedly difficult [5, 13, 16]. Certainly, the availability of cheap printed circuit board (PCB) manufacturing and assembly services has made one aspect easier than it used to be [9]. But designs that involve anything beyond a single, simple PCB—such as multi-board designs, exotic components, enclosures, mechanical parts, non-standard assembly techniques or operating outside a domestic environment—introduce dependencies on different disciplines and multiple commercial partners. This can make hardware hard [8].

Despite the challenges of developing an initial hardware prototype and then scaling up to deliver tens, hundreds or perhaps even thousands of units, experience shows us there can be clear benefits. In addition to the prototyping platforms mentioned above, three examples of hardware devices born in the HCI research community and subsequently successfully scaled up to great effect are:

- **The SenseCam wearable camera.** A handful of prototype devices illustrated the potential of SenseCam for people with memory impairments [12], motivating a scaling up of production. Initially a few hundred devices were built by the original research team for use by other researchers and clinicians in the community, and subsequently the device was licensed commercially as products from Vicon [27] and OMG Life [7]. Over 230 peer reviewed publications and 8 Ph.D. theses that leveraged one of these devices or data recorded by them have been published [23] and many users reported significant benefits from using them [26].
- **Wrist-worn motion logging devices.** Projects that leverage wrist-worn motion sensing for detection of gestures and activities have been explored by many researchers in the HCI community. Two examples which were successfully scaled up are the HedgeHog device [24] developed at Technische Universitat Darmstadt and devices from Axivity [2] based on work from Newcastle University's OpenMovement team [22]. In the latter case, around 50k devices have been manufactured to-date for use in various clinical settings, with an estimated user base of between 500k and 1M. This adoption has resulted in over 130 publications [2].
- **The eSense multi-sensory earable platform.** Nokia Bell Labs developed eSense [15, 21] as a platform for personal-scale behavioral analytics, with the aim of sharing it with the research community. The 1k units produced and distributed by the time of writing have already had a deep impact, being adopted by 70 research groups across 20 countries and resulting in over 50 research publications to date [18]. An improved device is currently under development.

The above research projects have undoubtedly had a significant impact in their respective research communities, as well as a positive impact with specific end users. However, while there are many tools to support prototyping, there are relatively few to support the on-going delivery of devices. Anecdotal evidence from researchers involved in these projects tells us that the hardware scaling process that underpins broader impact requires a significant investment of time, effort, and money.

This panel brings together a diverse set of established academics in the field of HCI, all of whom have experience developing or deploying novel hardware to further their research agendas. Collectively they will discuss the development and evaluation of novel hardware in an HCI research context. Is developing and scaling hardware *really* hard? Is it getting easier over time given the continuing evolution of tools and services, or do evolving technical, commercial, legislative and geo-political factors collectively conspire to make things harder, especially when considering the need for reliable replication? What types of research are unlocked through novel hardware, how valuable are the potential insights, and how do we measure impact? How can and how should the research community measure investments in hardware development and scaling and assess any opportunity costs relating to alternative HCI research that might be foregone as a result? Are there things that we can do collectively to generate more value from our hardware development efforts, perhaps by making concerted efforts to maximize our use of research prototypes across the community and ensuring ongoing availability?

2 PANEL FORMAT AND TIMING

To discuss these topics we propose a six-person hybrid panel[1] with one in-person moderator. The moderator will start the session by taking 3 minutes to describe the high-level topic, giving examples of key questions that will be considered. Then the moderator will introduce the panelists who will themselves each take two minutes to summarize their experience with research hardware, optionally supported by one or two slides that they have supplied ahead of time.

Following this, the moderator will slowly move through the following list of questions. There will be up to 12 minutes for each question, with around 6 minutes for comments from panelists and up to 6 additional minutes for contributions from the audience. Both panelists and audience members will be asked to keep their contributions to between one and two minutes each, although this may be adjusted at the moderator's discretion if appropriate. In addition to spoken questions and comments, typed contributions from the in-person and remote audiences will be encouraged, if possible. We would also like to engage with attendees asynchronously via the SIGCHI progressive web app, to raise awareness of the topics that will be covered. Finally, we will consider using a live interactive polling system such as Slido and/or an online real-time collaboration tool like Miro to solicit broader audience sentiment relating to the questions as the panel session progresses. In these ways we will strive to uncover the full range of perspectives relating to each question while driving audience engagement. The questions will be:

- Is developing hardware actually hard, or is this a myth? And either way, is it getting easier or harder?
- What are the benefits of developing and scaling custom hardware in HCI research?
- What is the opportunity cost? Could the community better spend its time elsewhere?
- How can researchers be most effective in developing and scaling hardware, and what help or incentives could facilitate this?
- Should the community develop new ways to evaluate and recognize hardware development and deployment?

To summarize the anticipated timeline for the panel, the 15 minutes of introductions will be followed by an hour of discussion and debate. This hour will be split into the five topics listed above, with 12 minutes for each. Should any time remain at the end, the floor will be opened for an interactive discussion with the hybrid audience.

[1] *i.e.* held in-person with the ability for panelists and attendees to participate virtually if preferred

3 MODERATOR AND PANELISTS

The panel includes two organizers (one of whom will be the moderator) and five additional panelists, all of whom have experience developing and/or deploying research hardware. None of these authors are focused on hardware only; they have a range of other research agendas that span the broad domain of HCI, including software, systems, design, interaction, accessibility, sustainability and social science. This "two-plus-five" structure means the panel will be well-placed to consider questions concerning hardware in a broader context. We have also strived for balance and diversity in the make-up of the panel to reflect the community's values.

Steve Hodges (co-organizer + panelist) is a Senior Principal Researcher at Microsoft Research. He strives to create new hardware-plus-software solutions that make computers more useful to individuals and to society, and builds tools that inspire and empower others to do the same. He works at all scales from prototype to production, and his work has contributed to millions of devices with tens of millions of users spanning domains such as education, assistive technologies, mobile devices and the internet of things. His work includes the BBC micro:bit, SenseCam, Azure Sphere and .NET Gadgeteer. Steve is a Fellow of the IEEE and the IET.

Per Ola Kristensson (co-organizer + moderator) is a Professor of Interactive Systems Engineering in the Department of Engineering at the University of Cambridge and a Fellow of Trinity College, Cambridge. He is a co-founder and co-director of the Centre for Human-Inspired Artificial Intelligence at the University of Cambridge. He has experience in the commercialization of several research projects, including gesture typing, dwell-free eye-typing, and mechanical exoskeleton gloves for force-feedback in virtual reality. He was recognized as an Innovator Under 35 (TR35) by MIT Technology Review and has won an ACM UIST Lasting Impact Award.

Josiah Hester (panelist) is the Allchin Chair and Associate Professor in the College of Computing at Georgia Tech. He designs and deploys tiny computers that last for decades, supporting applications in sustainability, healthcare, interactive devices, and education. He was named a Sloan Fellow in Computer Science in 2022 and won an NSF CAREER in the same year. He was named to Popular Science's Brilliant 10, the AISES Most Promising Scientist, and won a 3M Non-Tenured Faculty Award in 2021.

Antonio Krüger (panelist) is a Professor of Computer Science at Saarland University and CEO and scientific director of the German Research Center for Artificial Intelligence GmbH (DFKI). He is a co-founder of the Saarbrücken-based technology company Eyeled GmbH, which focuses on the development of mobile and ubiquitous information systems. Many of his research findings have found their way into applications in retail and other industrial domains. He has published more than 200 scientific articles and papers in internationally recognized journals and conferences and is member of several steering committees, editorial boards and scientific advisory committees.

Jennifer Mankoff (panelist) is the Richard E. Ladner Professor in the Paul G. Allen School of Computer Science & Engineering at the University of Washington. Her research is focused on accessibility through giving people the voice, tools and agency to advocate for themselves. She strives to bring both structural and personal perspectives to her work. For example, her recent work in fabrication of accessible technologies considers not only innovative tools that can enable individual makers but also the larger clinical and sociological challenges to disseminating and sharing designs. Similarly, her work in the intersection of mental health and discrimination uses sensed data to explore how external risks and pressures interact with people's responses to challenging moments.

Patrick Olivier (panelist) is a Professor in the Department of Human Centred Computing at Monash University in Australia where he leads the Action Lab, a multidisciplinary research group comprising impact-focused researchers working at the intersection of communities, technology and social innovation. A key element of Patrick's work is a commitment to the creation of open source software and hardware. Notable examples include the OpenMovement AX3 accelerometer which was designed for the largest study of physical activity ever conducted (over 100k participants) and now the most widely used monitor by clinical researchers across the world.

Yvonne Rogers (panelist) is Professor and Director of the University College London Interaction Centre in the United Kingdom. She has received the ACM SIGCHI Lifetime Research Award and been elected as a Fellow of the Royal Society in 2022. Other awards include an Outstanding Collaborator Award from Microsoft Research, the Royal Society Robin Milner Medal (2021), and an MRC Suffrage and Science Award (2020) for being one of the leading women in mathematics & computing. She a Fellow of the ACM and the British Computer Society and a member the ACM CHI Academy. She is one of the authors of the definitive textbook on Interaction Design and HCI that has sold over 300k copies worldwide and has been translated into many languages.

4 EXPECTED OUTCOMES

As a result of attending the panel and participating in the discussion, participants will have a **greater awareness of the challenges of prototyping and delivering hardware for HCI research** and an idea of whether these are growing or lessening as the technological landscape evolves. Exposure to the discussions may inspire some to **start exploring hardware-related research ideas** for themselves, or to think about new collaborations. We also hope that attendees of the panel will subsequently be in a better position to understand the efforts of colleagues, simply because the **challenges, benefits and drawbacks of working in hardware will be clearer**.

5 RESOURCE REQUIREMENTS

This panel will require the typical A/V and teleconferencing support for a hybrid event. Panelists may well show one or two slides during their introductions (as mentioned above) and these will need to be projected in-room and also streamed to remote attendees. Similarly, one or more in-room cameras and microphones (including at least one wireless microphone) will be needed to ensure that remote attendees can participate fully.

Although the discussion will be streamed, we propose that remote attendees do not ask questions or share their perspectives by voice, but rather they will be able to ask questions through chat and these will be directed to the moderator and panelists. We hope this will allow more remote participants to engage with the discussion and also make it easier for the moderator.

In addition to in-room the equipment to support this hybrid event, the panel would need two student volunteers to manage the equipment—ensuring the computer(s) are correctly signed in and ready for the event, that remote attendees had no technical issues, and helping the moderator to monitor the chat, etc. One student volunteer will be necessary for passing the wireless microphone around the room for questions from the in-room audience.

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