Actuated Materials and Soft Robotics Strategies for Human-Computer Interaction Design

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ABSTRACT

The fields of programmable matter, actuated materials, and Soft Robotics are becoming increasingly more relevant for the design of novel applications, interfaces, and user experiences in the domain of Human-Computer Interaction (HCI). These research fields often use soft, flexible materials with elastic actuation mechanisms to build systems that are more adaptable, compliant, and suitable for a very broad range of environments. However, at the intersection between HCI and the aforementioned domains, there are numerous challenges related to fabrication methods, development tools, resource availability, nomenclature, design for inclusion, etc. This workshop aims to explore how to make Soft Robotics more accessible to both researchers and nonresearchers alike. We will (1) investigate and identify the various difficulties people face when developing HCI applications that require the transfer of knowledge from those other domains, and (2) discuss possible solutions and visions on how to overcome those difficulties.

CCS CONCEPTS

• **Human-centered computing → User interface toolkits**; • **Hardware → Emerging interfaces**.

KEYWORDS

Programmable Materials, Soft Robotics, Fabrication, Design Tools, Tangible Interfaces, Interaction Design, Fluidic, Pneumatic, Shape Change, HCI

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1 BACKGROUND

Human-computer interaction (HCI) and interaction design are currently experiencing a growing interest in novel actuation strategies, advanced materials, and *Soft Robotics* [7, 31]. HCI researchers are exploring the potential of these emerging fields to create novel user experiences and interactive interfaces. In HCI design, the mechanical compliance of soft devices [8] presents an advantage over their rigid counterparts, because they conform to the body or surface [31]. The adaptation of soft robotic principles, technologies, and actuators into the HCI domain enables more natural and organic user interactions that leverage the unique characteristics of soft robots and the ability to programmatically control the physical structures at the material level [9]. Example characteristics include electrical conductivity under large strains [10], thermoregulation at thin form factors [27], high energy density [3, 28], self-powered actuators [39], computation on non-silicon-based and deformable substrates [11], on-demand stiffness control [35], self-healing sensors [34], and others [13]. An exploration of these abilities extends the design palette for HCI researchers, which we believe has a disruptive potential that deserves more focused attention by the CHI community. Soft Robotics often use affordable materials and technologies, which also makes them attractive for personal fabrication experiments, whether in research labs or DIY projects. Research prototypes based on soft devices and actuated materials have been demonstrated to enable novel interaction paradigms and user experiences [2, 12, 17, 33, 36–38] and have also been used to create devices and interfaces that promise to render low physical impediments to the user [9, 21]. We foresee that this ongoing paradigm shift transforms the HCI design space from rigid objects towards compliant, multimodal, and highly integrated user interfaces [15]. The application examples demonstrated thus far include on-skin sensors allowed by nanometer-thin arrays of conductive and dielectric membranes [20, 25], stretchable optical fibers that can reconstruct the hand pose and external interaction [4], haptic arrays enabled by fluidic elastomeric actuators [5, 6, 19, 26], stretchable sensor skins on inflatable structures [16], soft exoskeletons powered by artificial muscles [14, 22, 24], electroluminescent and stretchable screens [23], and many others.

The proposed one-day workshop will provide a space to reflect upon the creation processes, challenges, best practices and application potentials of the aforementioned (and similar) examples, and use them as starting points to explore critical questions on

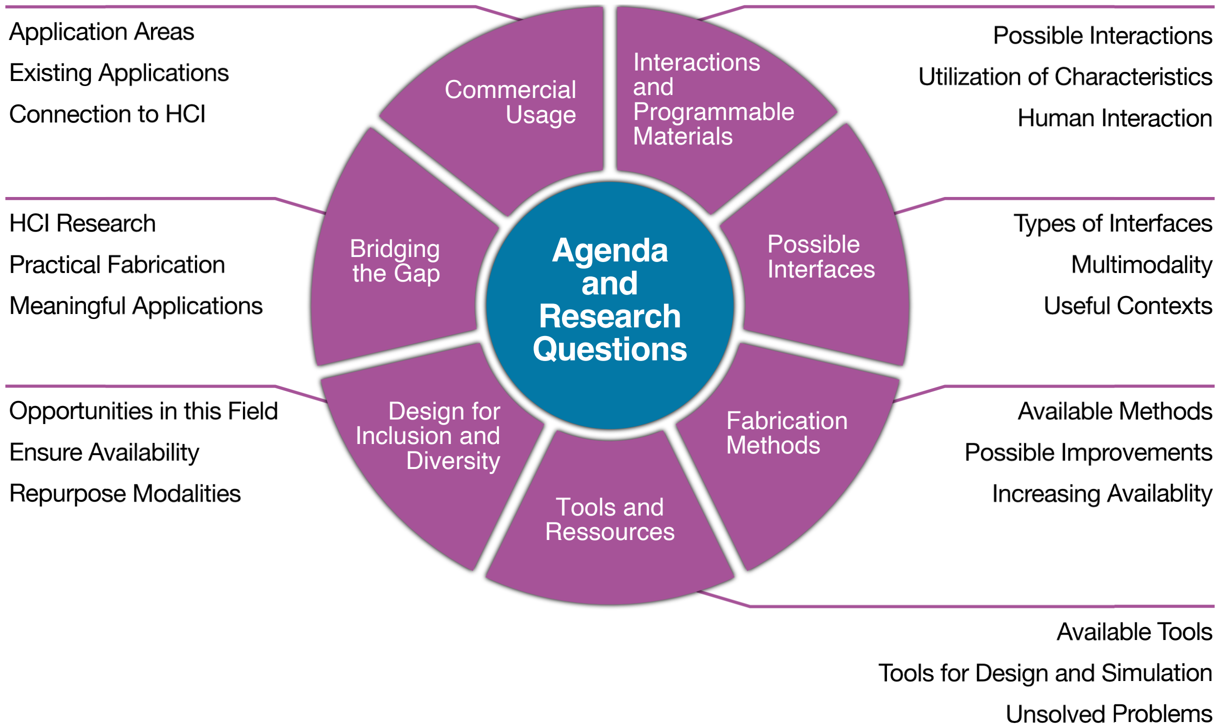

Figure 1: Research questions and challenges for Soft Robotics which will be discussed during the workshop.

how HCI researchers can benefit from a transfer of fabrication-, design-, and actuation strategies from recent research on soft robotics and programmable materials. The workshop will accommodate around 30 participants and enable them to discuss and exchange their experiences of the interplay of HCI and Soft Robotics.

2 RESEARCH QUESTIONS AND AGENDA

The *Actuated Materials and Soft Robotics Strategies for Human-Computer Interaction Design* workshop at CHI 2022 attempts to (1) highlight the relevance of programmable matter, actuated materials, and Soft Robotics in HCI, and (2) to bridge the gap and address the challenges with transferring knowledge from those domains to HCI. We will be bringing experts from all the relevant domains. The workshop focuses on technologies (and their fabrication methods) that are mature enough to be applied as interaction substrates. Selected topics from fundamental material science and soft robotic research are discussed in the context of an interface case study or application example. Special emphasis is put on stimulating the exchange of ideas between researchers that are active in different application areas of HCI such as health & elderly care, engineering, learning, wearables, telepresence, tangible user interfaces, etc. to identify novel application areas beyond the traditional scope of soft robotic research.

The central questions and challenges that arise when Soft Robotics strategies are leveraged in the context of HCI research are outlined in the following and serve as a basis for deeper discussions during the workshop (see also fig.1).

2.1 Novel Interactions through Programmable and Actuated (Soft) Materials

Programmable materials open up the potential for e.g. autonomous expression of the material in different scenarios. What new interactions are enabled by programmable materials? Which material characteristics can be utilized for interaction? How can humans interact with those materials?

2.2 Interface Case Studies and Examples

What type of interfaces are possible using Soft Robotics. Examples are visual, haptic, audio, audiovisual and other multimodal soft interfaces [17, 18, 30, 32]. How can they be implemented into applications that are of interest to the HCI field? What are the different modalities? What are their affordances and how can users interact with these interfaces? In which contexts would they be useful or helpful?

2.3 Fabrication Methods

Which fabrication methods are available to HCI researchers/hobbyists, and which are not? What are the fabrication pipelines, required work environments, materials, and equipment? How costly are these in terms of money and time? How can fabrication methods be made more accessible, affordable, faster, and simpler for everyone?

2.4 Tools and Resources

What tools and resources are needed or would be helpful for designing, simulating, and prototyping projects that utilize programmable and actuated materials? Some examples are silicone 3D printers, development platforms like FlowIO [29], websites like the Soft Robotics Toolkit [1], and various CAD tools. How can novel tools and resources be made available to all interested users? What tools and resources do you find lacking in your own workflow that would greatly increase your productivity if they existed? How can we lower the entry barrier for people from technical and non-technical backgrounds to start incorporating programmable materials into their projects?

2.5 Design for Inclusion and Diversity

There are examples in which Soft Robotics are already used for an inclusive design including brailles [1] for visually impaired individuals, exoskeletons for motor skill support, mental and affective health support in elderly care and related areas. What other alternative contexts exist where the affordances of Soft Robotics can be explored for inclusion and diversity? How do we make Soft Robotics useful and valuable in these contexts? How can we develop interfaces to be readily available to those working in design for inclusion? What are the context-specific benefits of Soft Robotics in design for inclusion and diversity? How can soft robotic modalities, such as ergonomics and customization, be repurposed in these contexts?

2.6 Bridging the Gap

We see a potential for research in the areas of fabrication, tools, and meaningful applications within HCI. But what can be done to bring together HCI research, practical fabrication, and novel areas of use? What other research fields can be connected to HCI such as Materials Science, Soft Robotics, or Microsystems Engineering?

2.7 Application Examples and Commercial Usage

Soft robotics and programmable materials are used in various application areas such as prosthetics, robotic surgeries, gaming, training, industrial robotics, personal protection, and simulation. We would like to collect and discuss current commercial soft devices and applications for HCI.

3 ORGANIZERS

The workshop is organized by an interdisciplinary team of researchers who are currently working at the intersections of (Soft) Robotics, Material Science, Interaction Design, Wearables, and Human-Computer Interaction. Therefore, the authors provide a wide range of experiences in designing, fabricating, and applying soft robotics in their different fields. The expertise and experience accumulated by the organizers provide the base for discussing the research question.

Ozgun Kilic Afsar. is a Ph.D. candidate at KTH Royal Institute of Technology, and a Research Affiliate at MIT Media Lab. Her current research focuses on integrated soft robotic fibers and textiles that correspond to the dexterity of human biomechanics. Such active textile systems feature multimodal haptic feedback to kinesthetically support skill acquisition and transfer in creative movement practices. This work has recently been featured as a cover story on MIT News. She is currently exploring robotic upper-bodyware's potential to allow for intergenerational interactions in the context of opera, such as two experts singing a duet across time and space. Her aim is to generate a tangible skills database to safeguard somatic skills in the form of haptic notations through robotic materials.

Jose Barreiros. received his Ph.D. (2021) and MSc. (2020) in Systems Science at Cornell University with a focus on robotics. His research lies in the intersection of soft and traditional robotics, machine learning, and haptics. He aims to push the boundaries of artificial touch from the learning and hardware perspective to achieve ubiquitous human-like haptic perception for embodied AI agents. He has worked at Facebook Reality Labs and TieSet –a seed-stage startup working in privacy-preserving AI. In 2021, he continued his education as a research fellow at ETH Zurich working on haptic perception for quadruped robots at the Robotic Systems Lab.

Anke Brocker. is a researcher and Ph.D. candidate at the Media Computing Group at the RWTH Aachen University in Germany. Her research focuses on the systematic exploration of soft robotics fabrication methods and materials to implement them into Smart Jewellery and Wearables. She aims to make use of soft robotics as an additional communication channel between users, e.g. on an emotional level or by rendering haptics on the wearer's skin. She is part of the Fab Lab Team as Fab Lab Administrator at the Media Computing Group and has been active in teaching fabrication methods and possibilities that the Fab Lab offers. Further information: https://hci.rwth-aachen.de/brocker

Kristian Gohlke. is a researcher and lecturer at the Bauhaus-University Weimar, Germany. His ongoing Ph.D. research project is focused on 'Exploring Bio-Inspired Fluidic Soft Actuators and Sensors for the Design of Shape-Changing Tangible User Interfaces'. Gohlke is also a co-initiator of the ongoing *Bauhausinteraction Colloquium* [LINK: http://bauhausinteraction.org/cat/bauhausinteraction-colloquium/], an interdisciplinary lecture series that addresses contemporary topics in technology, arts and design, and the humanities through talks of internationally renowned speakers. As part of his ongoing freelance engagements he consults, creates, and realizes interactive projects for clients such as Native Instruments, Red Bull, automotive R&D startups, or the LEGOLAND theme parks, as a professional UX- and Interaction Design consultant. He is currently involved in developing concepts and prototypes for future assistive care technologies as part of the interdisciplinary ReThiCare[2] project group.

Ali Shtarbanov. is a researcher, platform designer, and Ph.D. candidate at MIT Media Lab who holds degrees in Electrical engineering, Physics, and Human-Computer Interaction (HCI), and is currently pursuing his Ph.D. in HCI with a focus on making soft robotics prototyping seamless and accessible to everyone. Ali is the inventor of the open-source FlowIO Platform for soft robotics which is currently being used by dozens of researchers, students, and designers in over 10 countries; he is also the creator SoftRobotics.IO[3].

[1]https://softroboticstoolkit.com

[2]http://www.rethicare.info/

[3]https://www.softrobotics.io

Ali's works have won numerous design and research awards including Gold Medal at the ACM SRC, Best Poster Award at IROS, If Design Talent Award, A Design Award, Hackaday Prize, and others. Ali has also served as a judge and reviewer for various venues including Hacking Arts, IEEE HAVE, and MIT Technology Review 35 Under 35 Europe.

Sören Schröder. works as a student assistant at the Media Computing Group (RWTH Aachen University), where he is involved in the ongoing research in novel interaction methods regarding wearable computational devices. Additionally, in the context of his master's thesis he designs, manufactures, and actuates soft robots to investigate their potential as a communication channel when integrated into jewelry.

4 WEBSITE

The workshop call for participation will be available online at https://softrobotics.io/chi22. An online registration form (e.g. via Google Forms) will allow interested researchers and other practitioners to submit their expression of interest. The complete program details will be posted on the website, once finalized, including the list of all speakers, participants, and organizers. A post-workshop section will also be posted on the website after the conference with extra materials, presentations that our participants are willing to share, relevant notes, sketches, ideas, and other takeaways from the workshop. This webpage will become one of many soft robotics workshop pages that are going to be posted on the softrobotics.io website over the coming years. The website will thus serve as a resource, for years to come, where interested researchers, makers, artists, and students can come to learn about the latest developments in the field, find inspiration for new projects and ideas, or seek potential collaborators.

5 PRE-WORKSHOP PLANS

The following subsections describe the preparations that will be made by the organizers, including the resources available to the participants.

5.1 Hybrid Workshop

Our workshop will take place in a hybrid format. About 30 participants can take part in our workshop. We are flexible about how many participants will take part virtually and how many onsite. But for a reasonable execution, we intend to have at least five participants for each, the virtual and the onsite, track. The maximum number of participants for the onsite workshop is 15. For virtual participation, we plan to provide an environment using an online tool. One option can be the tool gather.town [4]. We are aware that this platform comes with some issues regarding inclusion, thus we are open to more inclusive options that might be provided by the conference. No matter what tool will be used we plan for a tutorial session before the workshop to allow all participants to get comfortable with the tool.

[4]https://www.gather.town

5.2 Impulse Keynotes

We are going to invite three speakers to give impulse keynotes at different times during the workshop. These keynotes will allow participants to gain knowledge about some of the latest research in the area of programmable matter based on soft robotics. Nevertheless, these keynotes aim to facilitate discussion about the presented topics in which participants will have the opportunity to talk and discuss with each other during the Q&A session (see fig. 2).

5.3 Materials for Participants

During the workshop, we will aim to have a soft robotics starter kit with a FlowIO device [29][5] for several of the participants, where the total number of kits will depend on the availability of resources and funding. Since CHI'22 is planned to be a hybrid conference, we will try to have some kits available at the conference venue, and some that we ship to participants. We plan to provide asynchronous materials such as pre-recordings of the impulse keynotes and PDFs with the topics, schedule, and explanations of the tasks for the focus groups on the website for participants with connection- or accessibility-related issues. If participants are not able to join the online tool in the virtual group they should be able to work on their own with the provided device. Asynchronous material will additionally be distributed to the participants beforehand. Participants will be encouraged to bring interesting demos they can show and talk about, and/or materials, tools, or projects of their interest to work with during the hands-on activities. More information regarding the hands-on part of the workshop will be disseminated four weeks prior to the conference start date. Participants can keep any artifacts they develop during the workshop, but they will have to return any FlowIO devices provided to them.

5.4 Workshop Advertisement

The organizers have extensive networks of experts and researchers in both academia and industry which will be leveraged to ensure that key people in all communities, that may regard the workshop topic as relevant and might consider participating, are made aware of this workshop. The call for participation will be sent to numerous institutional mailing lists and also be shared on relevant social media channels (e.g. LinkedIn, Twitter, etc.). Additionally, we will advertise the workshop on the homepage of the softrobotics.io website, which has over 800 unique visitors per month, and share it with the website mailing list of over 400 people, most of which are soft robotics researchers. Additional press releases will be made through the supporting institutions' websites.

6 WORKSHOP STRUCTURE

The following sections describe our main topics and the planned content for the workshop.

6.1 At the workshop: Kick-Off & Connections

The workshop will be opened with a brief individual introductory round ('speed dating') to encourage participants to connect with each other and exchange contact details. Each participant will get 60 seconds to introduce herself to a random member of the workshop

[5]https://www.softrobotics.io/flowio

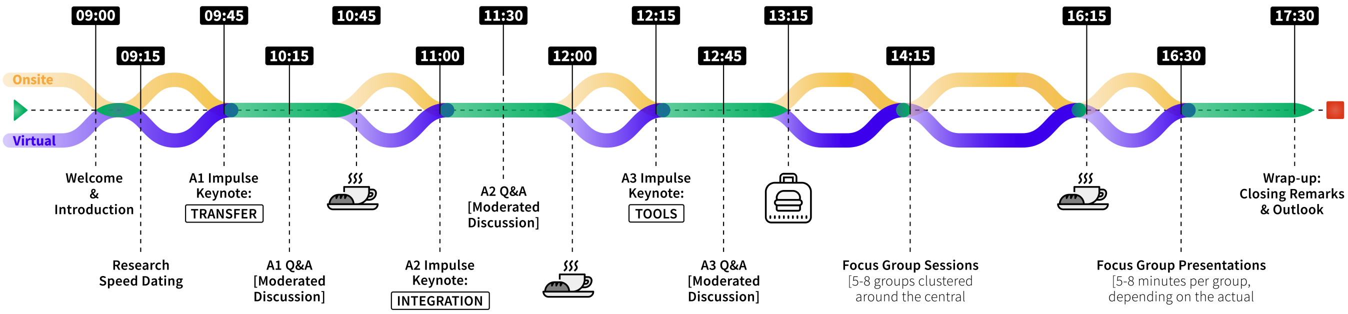

Figure 2: Hybrid workshop schedule. The yellow color (onsite workshop) and the purple color (virtual workshop) represent when the workshop groups will work separated. The green color visualizes which parts of the workshop will happen jointly.

e.g. with a short verbal description of her research and goals and intentions for attending the workshop etc. Six consecutive 60-second rounds will be conducted to stimulate communication among workshop participants. After the speed dating, the authors will give a 15-minute introduction to the workshop topic and an overview of challenges in leveraging soft robotics and related materials for Human-Computer Interaction Design.

The workshop will be organized around three main areas (A1, A2, A3) that focus on relevant aspects and challenges of working with Soft Robotic technology in HCI:

A1 - TRANSFER: *Novel Materials & Actuated Structures* – Designing novel user-interface prototypes or interactive experiences for hands-on exploration with users is oftentimes challenging, especially when prototypes are based on experimental material structures and sensing principles such as those used in soft robotic research. Application specific requirements in HCI-prototyping require modification/adaption of materials and structures to leverage their interactive potential or make them robust enough for specific application domains. This workshop section will highlight and discuss best-practice examples and transfer strategies on how HCI research can benefit from ongoing developments in soft robotics research and vice-versa.

A2 - INTEGRATION: *Interaction, Sensing, Control, & Applications* – This section highlights recent developments and strategies for leveraging soft robotics inspired sensing, control, and actuation methods in interactive systems and Human-Computer Interfaces. One focus will be on novel sensors made from soft and malleable materials, and how they can be used to sense user input. Special attention will be brought to challenges of integration, the capabilities and the requirements for control systems, and the availability of resources for self-learning.

A3 - TOOLS: *Design Strategies, Fabrication Processes, Simulation & Modeling* – Standard fabrication tools and processes are often not sufficient to produce soft-robotics inspired actuators and sensors and actuators. Some processes can be modified and adapted to make them suitable as prototyping tools. However, to enable truly novel interaction paradigms, the prototyping processes themselves have to be researched and developed from scratch. Non-material scientists and interaction designers who intend to create interactive experiences based on soft robotics technologies are in need of predictable and reproducible prototyping results. Those results should be aimed at robustness, material efficiency, and accessible platforms. This workshop section will be completed by illuminating recent efforts and needs for modeling tools aimed at simulating and designing soft robots.

Each section will be kicked-off by one of the three high-profile speakers from different backgrounds at the intersection of interaction design and soft robotics. Each of those speakers will be invited to give an impulse keynote to highlight their perspective on the research area. These three keynotes will be distributed during the day and work as openers for the different sections of the workshop. A moderated Q&A session and discussion after each keynote will provide an opportunity to further intensify the exchange among all workshop participants, or allow the speakers to elaborate more deeply on specific topics of interest.

6.2 Materials and Resources

For the onsite participants, we will need space in the workshop room to work on group tables, especially to prototype with hardware in the afternoon session. For the virtual participants, the workshop room needs a good camera and a big display. The morning impulse keynotes should be live-streamed (pre-recordings will also be available). The discussion of the presented topic will happen jointly with the onsite and the virtual group. The display may show the online environment used by the virtual participants to provide a contact point between virtual and onsite participants during the workshop.

7 POST-WORKSHOP PLANS

To disseminate the results of the workshop, all accepted submissions to the workshop will be made public on the website. We also intend to compile a follow up publication of the workshop that should include the accepted submissions and will be extended with additional material provided by the keynote speakers and generated during the workshop. The format of that follow-up publication may be a poster presentation or a workshop report. This will be decided upon the generated results. We would like to offer this workshop again based on the success and ideas of the 2022 workshop.

8 CALL FOR PARTICIPATION

For this one-day workshop, we invite submissions that demonstrate challenges and new opportunities related to the design, fabrication, implementation, and deployment of soft robotic applications or tools. Our goals are to identify the various pain points that people face when developing projects involving soft matter, what new tools and techniques are needed to address them, and what other opportunities exist to make the design, prototyping, and control of soft programmable materials more seamless and more accessible to HCI researchers and other makers. Submissions should be 2-4 pages long in the CHI Extended Abstract format and may be on any topic that is consistent with our aforementioned goals. The due date for submissions is February 24, 2022. Participants will be selected based on the quality and clarity of their submissions as they reflect the interests of the workshop. We will notify people by March 21, 2022. The workshop will take place as a hybrid event, so virtual or onsite attendance is possible. It is important to note that at least one author of each accepted submission must attend the workshop, and all participants must register for both the workshop and at least one day of the conference. For more information and the latest updates about the workshop, see https://softrobotics.io/chi22.

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