Democratizing Computational Materials For the Creation of IOT

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The recent advances in material sciences prompted the rise of computational materials, but also inspired us to rethink the role of Internet of Things (IOT). To bridge the gap between them, I illustrated the relations between human, computational material and IOT, and envisioned that the democratization of computational material is a key to realize ubiquitous IOT because the material can naturally afford the interaction and fabrication of IOT. Then, I showed the four challenges (i.e. interactivity, makability, computation, and communication) that we need to overcome. I present my past and future research as examples to solve the challenges in the democratization of computational material. I concluded my thesis by discussing the potential benefits and contribution.

Additional Key Words and Phrases: Internet of Material, Smart Material, Computational Material, Democratization, Internet of Things

ACM Reference Format:
Te-Yen Wu. 2021. Democratizing Computational Materials For the Creation of IOT. 1, 1 (October 2021), 7 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 MOTIVATION AND BACKGROUND

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." Mark Weiser's seminal vision in the early 90s opened the era of ubiquitous computing [12]. Fastforward to today, academia and industry have continued to integrate computation into everyday things. One of borne fruit is the Internet of Things (IOT), which delivered many researches and products such as smartphones, smartwatches, smart televisions and smart glasses that have merged into our everyday life. However, despite of the advancements in IOT, we are still too separated from a complete hybrid of the physical and digital worlds. One of the reasons is that the IOT devices are currently created using the hardware with distinctive characteristics (e.g. rigid), which are easily distinguished from the real everyday objects.

The rise of computational material gives a solution to this problem [1], but also inspired us to rethink the IOT. To bridge the gap between them, I illustrated the relation between human, thing and material, which was shown in Figure 1. This illustration explained that in the past, the natural interactions and fabrications afforded by the regular materials help the democratized creation of everyday things (Figure 1a). However, in the present, the IOT though provide more advanced humam-computer interactions but not composed of the materials that afford interactions and fabrication, and instead the complex integrated circuits that are sophisticatedly packaged into existing objects (1b). The such creation of IOT resulted in the high cost and high barrier to impede traditional industry to implement smart everyday objects. To liberate the technology from the current "IOT devices", the computational material that can afford rich interactivity and makability is a key for the democratized creation of internet of things (Figure 1c).

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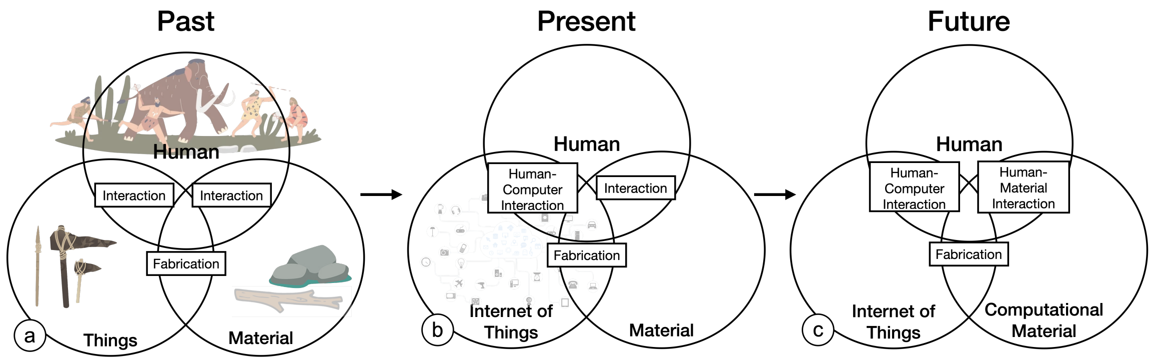

Fig. 1. The relations between human, thing and material in the past, present and future.

2 VISION

I envisioned that the democratization of computational materials can lead to the realization of ubiquitous IOT. In the vision, all materials become computational and can naturally afford interactions and fabrications to human. They are cheap, and widely available in the stores due to the massive production. Any person can directly interact with and purchase them in the stores to make things. In the fabrication of smart everyday things, the designers, makers, and manufacturer can treat these computational material as regular materials. They do not need to learn extra knowledge to use these material. The existing production line of things could also keep same. Yet, the new interactivity, computation and internet would be seamlessly integrated into the things in the fabrication. Then, the everyday objects would smoothly become interactive, computational and connected.

3 RESEARCH CHALLENGES

To democratize computational materials, there are four research challenges, respectively the interactivity, makability, computation, and communication. In the followings, I described them in the detail.

3.1 Interactivity

The limited interactivity of computational materials would hinder the ideation and development of smart everyday things, which would potentially cause the failure of democratization. Therefore, the computational material should afford more rich interactivity than regular material to the thing creators and manufacturers for making diverse things. But the research questions are what interactivity computational materials should have and how to implement the interactivity in the diverse materials. To address these questions, there are some prior researches that work on the investigation and implementation of interactivity of the materials such as textile [7, 9–11]. Yet considering the diversity of materials, we still need more HCI researchers, material scientists and electrical engineer to collaborate together to explore more technology for the interactivity for different materials.

3.2 Makablity

Makability is the ability of computational materials to afford the fabrications of things. A good makability of computational materials can allow any manufacturing machine, and any person from the kid to the adult to use the materials to make everyday things. To design the computational materials with the good makability, there are some research problems. First, we have to understand what fabrications different materials would afford so a complete investigation on it is needed. Next, we are required to explore more technologies that can tolerate the fabrication. Some prior researches have touched on this problem but not yet solved it [3, 4, 8, 13?]. One of the example is the cuttable interface proposed by Olberding et al. [8], who tried to make the circuitry of the paper-like sensor afford cutting with the simple shapes. Although it is a good start, the follow-up researches have not continued to address this problem (e.g. the more complex cutting shapes like the fashion design patterns). Furthermore, other than cutting, there are still many fabrications such as drilling, and screwing have not been discussed and considered in the design of computational material before. Thus, we need more researchers in the HCI community to solve this challenge together.

3.3 Computation

Computation means the resource that can perform logical operations on the information acquired from the human-material interaction. The insufficient computation would fail the interactivity and makability of computational material. Specifically, the firmware algorithm that can adapt to the after-fabrication material, and handle and process the interaction data from the material requires enough computation to run. The research line proposed by Abowd have started to tackle the problems related to the computation [1]. His prior article has demonstrated several examples that can harvest the energy from the environment and do some computing logical operations in material [2]. In addition, he also mentioned some remaining research questions including the programming interface of computation and the production of the “microchemicals” and nanoelectronic that are related to the challenges of computation. Aside from them, the distribution of the computational resources in computational material to afford fabrication is also another research problem that need to be addressed in the democratization of computational material.

3.4 Communication

To provide a more complete user experience for the IOT made from computational materials, the materials themselves must be able communicate with each other. Some communication technologies developed for IOT such as Bluetooth, Zig-bee, and Wifi are the candidates to solve this challenge. But, we also need to consider if these technologies can really carry the scale of computational materials, which maybe varies from tens to millions. An alternative way is that we could leverage the infrastructure of IOT for major wireless communication between things, and build physical or small wireless network structure in a thing for the inside computational materials to communicate. In doing so, the challenges such as the interface of reconfigurable network structure and the communication protocol still need more researches to address. On top of all of them, the security and privacy problem is the most important challenge in the communication that has to be solved.

4 RESEARCH PROGRESS

As I am a HCI researcher, my research line mainly emphasized on the interactivity and making of computational material, which are the challenges related to human. I will also touch a little bit on the computation and internet of computational material and shared the findings from my work.

4.1 Interactive Material

I have worked on five researches [5, 6, 15? , 16] that brought novel interactivity into material, specifically in textile. I selected the three of them to show my contributions in this area.

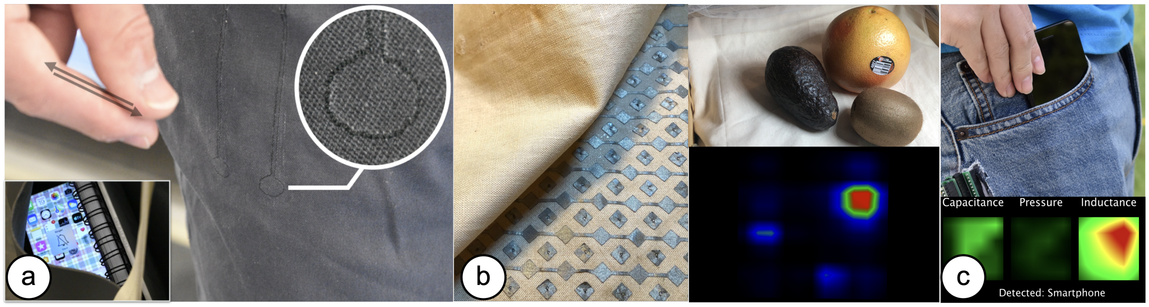

Fig. 2. Three interactive material. (a) a textile embroidery that can sense touchless gestures. (b) a fabric that can recognize objects (c) a pocket-based fabric that can detect objects and gestures.

4.1.1 Fabriccio. The first one is Fabriccio [14], which is a textile embroidery that can sense touchless gestures using Doppler motion sensing (Figure 2a). It consisted of a pair of loop textile antennas (one for transmitting and the other for receiving), made of conductive thread that was sewn onto a fabric substrate. The antenna type, configuration, transmission lines, and operating frequency were carefully chosen to balance the complexity of the fabrication and the sensitivity of our system for touchless hand gestures at a 10 cm distance. We evaluated the performance of the textile sensor through a ten-participant study. The study result yielded a 92.8% cross-validation accuracy and 85.2% leave-one-session-out accuracy for 11 touchless gestures as well as 1 touch gesture. Finally, we also demonstrated the smart things that can be created by this interactive embroidery, such as smart sofa, smart pants and smart t-shirts.

4.1.2 Capacitivo. Capacitivo is an interactive fabric that can recognize the nonmetallic objects on it such as fruits, dishware, and other types of objects that are often found around a home or in a workplace [15] (Figure 2b). Our prototype was composed of a 12 x 12 grid of electrodes, made from conductive fabric attached to a textile substrate in a simple fabrication method. We designed the size and separation between the electrodes to maximize the sensing area and sensitivity. We then conducted a 10-person study to evaluate the performance of the interactive fabric using 20 different objects, which yielded a 94.5% accuracy rate. We also showed some examples of smart things enabled by this interactive fabric, such as a tablecloth that can sense what objects on it, a basket lining that can recognize the inside fruits, and a textile coaster that can sense the liquid type in the cup.

4.1.3 Project Tasca. Tasca is a pocket-based textile sensor that detects user input and recognizes everyday objects that a user carries in the pockets of a pair of pants (e.g., keys, coins, electronic devices, or plastic items) [16]. We developed the prototype by integrating four distinct types of sensing methods, namely: inductive sensing, capacitive sensing, resistive sensing, and NFC in a multi-layer fabric structure into the form factor of a jeans pocket. Through a ten-participant study, we evaluated the performance of our prototype across 11 common objects including hands, 8 force gestures, and 30 NFC tag placements. We yielded a 92.3% personal cross-validation accuracy for object recognition, 96.4% accuracy for gesture recognition, and a 100% accuracy for detecting NFC tags at close distance . We finally showed our pocket-based sensor embedded into a jean to enable several applications.

4.2 Makable Computational Material

I am implementing a computational wood that can sense the vibration and also afford the fabrications to become different artifacts, furniture and infrastructures. In this research, I first investigated the common fabrications on the

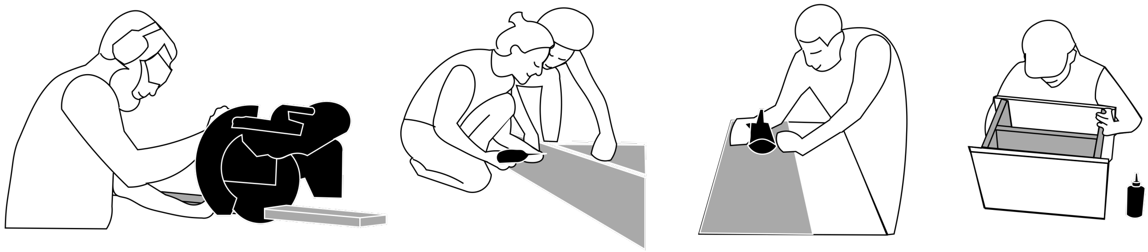

Fig. 3. The depicted picture of makable computational wood that can sense vibration.

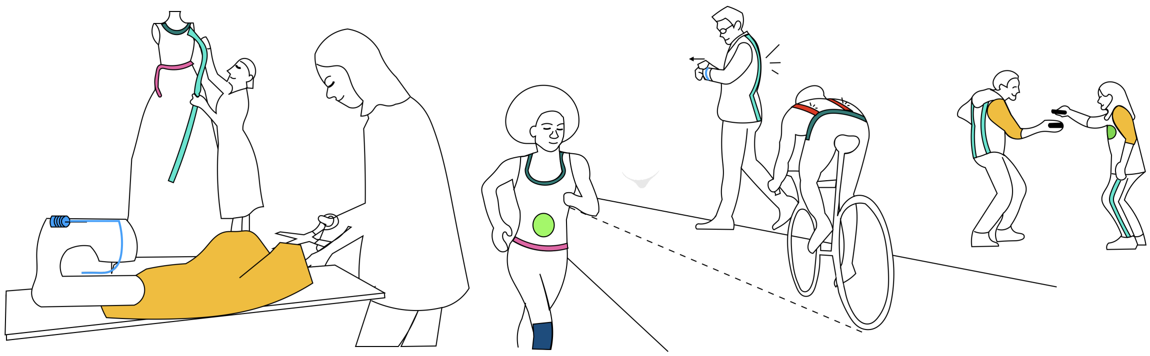

Fig. 4. The depicted picture of the realization of computational textile system

wood material from 300 Do-it-yourself (DIY) projects. The result yielded six fabrication approaches used in over the 50% of all DIY projects, including cutting, drilling, screwing, gluing, sanding and painting. Next, I will explore the technology that can afford these fabrications but maintain the high sensitivity to vibrations. I will conduct a series of experiments to study the performance of this vibration sensing wood in different sizes, thicknesses, wood materials, and hole and screw positions. Finally, I will recruit several makers to use this computational wood to fabricate different smart everday things like cutting boards, chairs, tables and floors. This research aim to finish in June, 2022.

4.3 Computational Material System

The last but not least part of my thesis is a proof-of-concept system that can embody the interactivity, makability, computation and communication in the textile material to demonstrate the practical potentials of my vision and also probe the user feedback about it. (4). I started by designing the imagined system stack for the computational materials, as shown in Figure5. In the system stack, there are five layers in the computational material. The topmost layer closest to the human is the interaction interface that provides rich interactivity to human. The second layer is the fabrication interface which is responsible to make material still functional after the fabrication . Below them, the algorithm layer is to adapt to the fabrication interface and realize the interaction interface. On bottom of them ,the computation layer and communication layer are respectively to run the algorithm and the communication protocol to connect to other computational materials in a thing. Then, a thing may include another programmable system to coordinate the different computational materials and also connect the thing to the internet. So in this research, I plan to implement the system stack in textile. I will first investigate the common textile materials used in the fashion projects but also the common

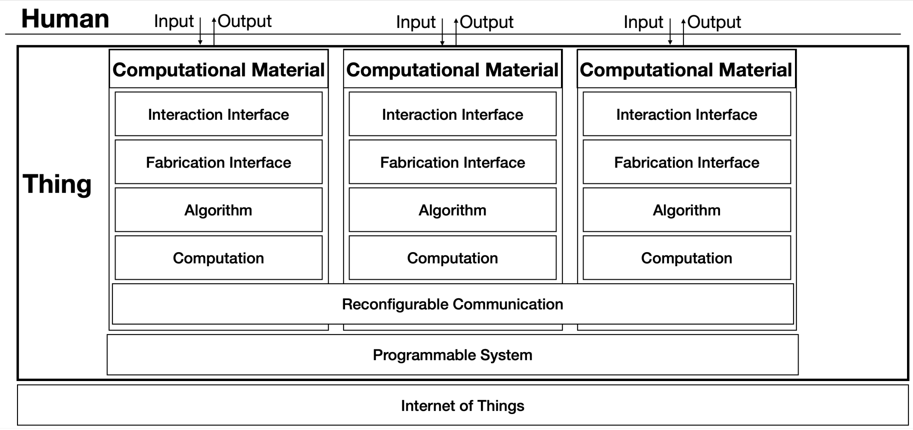

Fig. 5. The imagined system stack of computational material system.

fabrication approches. Next, I will design several interactive and makable textiles with the modular computing boards to offer the computation and communication capability. I will demonstrate several fashion projects which use our system to create smart garments. In the end of this research, I will discuss my findings for the future system of computational materials, including the perspectives on the power, and the production of computational material. This research also aim to finish in June, 2022.

5 BENEFITS, CONTRIBUTION AND FUTURE RESEARCH

In summary, the democratization of computational material can benefit IOT in three dimension. First, the computational material can bring the better form factor to the IOT. The smart everyday things will look more natural and feel more like the regular objects. Second, the production scale of a material can be much higher than a thing, which provide more spaces to drive the the cost down. Assuming an object may have million replicates in production, but the material could be billions and even trillions because a single type of materials can be used to make many diverse things. Third, the barrier to using material to fabricate internet-of-things is much lower than the current approach of using modular electronics and circuits to build IOT. After all, the experience of using electronics and circuits is almost none to common people, but regarding material, most people inherently know how to use a paper, a piece of wood to make the things.

The contribution of my thesis includes 1) the illustration of the relations between human, IOT and computational materials. 2) the proposed vision that depicted how the democratization of computational materials can liberate the creation of IOT. 3) the emphasis on the four challenges that we need to overcome for the democratization of computational materials. 4) the researches that contributed to bringing novel interactivity to the textile material. 5) the first research on how to implement a computational material that can afford the common fabrications and be seamless integrated into the everyday objects. and 6) the proof-of-concept system that can synthesize the interactivity, makability, computation and communication into the textile to demonstrate the practical potentials of my vision.

In the big picture of my vision, the thesis is a start. There are still many challenges (e.g. diverse material, and additional computation and communication challenges) that I need to address in the future. I will follow the directions described in my thesis until the day that computational materials are democratized.

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