Paper Summary

The Internet of Materials:
A Vision for Computational Materials

By:

Rockson Agyeman (11948833)

and

Kyriakos Lite (11948563)

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1 Introduction

Advances in every aspect of science and technology in recent years have had a positive impact on manufacturing. We can manufacture new materials that can sense, conduct computations and communicate. This gives rise to the era of the Internet of Materials (IoM). This era is about common objects made from everyday materials that behave as connected computational entities, also known as Computational Materials (CM). With these materials, the physical and digital worlds can be connected. Three key components are important for realizing the vision of CM and IoM.

- **Power**: When designing mobile computing devices, one of the important constraints taken into consideration is power. Creating CMs that can harvest enough energy to carry out their operations is a critical problem that needs to be solved.
- **Scale**: As predicted, it is now possible to produce more integrated circuits for lower prices. However, when the scale of integrating billions of things is considered, it can become very costly. Therefore, there is a need to consider cost-effective means of manufacturing CMs.
- **Form factor**: Last but not least, it is really important that we can manufacture CMs that are indistinguishable from everyday objects (i.e. objects that look like everyday objects, or when put on everyday objects they don't alter the look or the feel of those objects).

2 Computational Materials

Computational materials are manufacturable materials, preferably at a low cost and on a large scale, capable of harvesting energy or harnessing power through wireless power transfer to perform computational operations. Such materials must be able to perform logical operations, store information, sense the environment and act upon the environment to alter it. Below are four projects exploring computational materials at the Georgia Institute of Technology (Georgia Tech).

2.1 Self-powered Audio Triboelectric Ultrathin Rollable Nanogenerator (SATURN)

Saturn is a computational material that can sense vibration (e.g. sound). It is a passive sensor, i.e. it obtains the energy necessary for its operation from the environment. It has a low manufacturing cost and can be installed into various surfaces because of its flexibility. In combination with passive wireless communication solutions, these sensors can be connected to traditional computers also.

2.2 Optosense

Optosense is also a passive sensor that harvests power from ambient light and can sense the fluctuation pattern of ambient light to infer user activity and interaction on an objects' surface. Some usage examples are fluid level detection, step counting, and multi-touch gesture detection.

2.3 UbiquiTouch

UbiquiTouch is an inexpensive wireless touch interface that utilizes radio frequency (RF) backscatter to communicate with other devices wirelessly. This allows for everyday flat surfaces, for example, to be used to detect human touch and transform that into a 2-D coordinate that can be communicated wirelessly.

2.4 SilverTape

SilverTape is a novel fabrication technique which allows the printing of circuits onto non-planar surfaces. This technique offers flexibility, transparency, heat durability and water solubility. This novel technique opens a variety of new application opportunities.

3 Need for Computational Materials

Historically, the adoption of new technologies is based on practical applications that urge consumers to buy and companies investing in such applications. The big challenge for prototyping new and compelling user experiences is to demonstrate the value of a simplified large-scale distribution of practical solutions. Without a cost-effective way of prototyping solutions, the vision of CM and IoM may take very long to realize.

4 Additional Research Challenges

Solving the research challenges listed below are important for the advancement of CM and IoM.

4.1 Practical power provisioning

Considering the constraints of scale and form factor proposed for computational materials, harvesting energy, and direct wireless transmission of power should be investigated.

4.2 Production practices

It has been a common practice for years to follow Moore's Law and assume that advancements in computing manufacturing rely on *integrated techniques*. But there exist more ways to tackle mass production and the secret lies behind formulating a *bulk manufacturing* scheme for the production of CMs.

4.3 Programmable platforms

CMs are going to be used as a part of a larger system/platform. This comprises of:

a) the **CMs** that can interact with humans and with the environment to which they will be deployed. These CMs will be energy-constrained, maybe mobile and also wireless
b) an **infrastructure** that is unconstrained of energy and computing capabilities.

Designing these versatile platforms is a crucial challenge, especially the "Long-lasting" CMs that will require a re-programmable architecture to be configurable and tailored to various deployment requirements.

4.4 Value-sensitive design principles

The developers of CMs and IoMs must take into account societal values in the progress of their work. These new types of materials give rise to new possibilities and give rise to concerns about privacy. Therefore, it is really important to consider privacy-by-design. It is also important to consider other ethical actions like promoting the construction of CMs from renewable sources and/or be biodegradable and/or be nontoxic. Research and development of CMs should be implemented with consideration for shared societal values and ethics.

5 Thinking Differently

We have to change the way we are thinking and not rely on Moore's Law but consider new forms of progress; functional computational materials will get cheaper, self-sustainable, manufacturable at larger scales and more similar to everyday objects. One of the best ways to advance the vision of CMs and IoM is to seek influence from different fields of science.

6 References

[1]. Gregory D. Abowd, "The Internet of Materials: A Vision for Computational Materials", IEEE Pervasive Computing, 2020.