

A Note on Smart Textiles

I enjoyed reading “Smart Textiles: From Niche to Mainstream,” by Jingyuan Cheng and her colleagues in the July–Sep 2013 issue of *IEEE Pervasive Computing* (Wearable Computing department, pp. 81–84). In it, the authors state the following:

As a result, we envision a garment that’s “sensing ready” but doesn’t yet contain any active electronics. In the long term, such garments shouldn’t cost much more than comparable “dumb” clothing. Such “sensing ready” clothing could become the default in certain domains, such as sportswear. Although the sensing infrastructure has been adapted for the garment, it remains independent of the signal-processing step and can thus accommodate a broad variety of sensing modes and architectures.

This is precisely what was developed as the Wearable Motherboard (initially called a Sensate Liner) under funding from DARPA back in 1996. In the process, it laid the foundation for the field of smart textiles, because application-specific sensors and devices could be plugged into the “dumb” fabric infrastructure, which was akin to the motherboard inside a computer into which chips are plugged in.^{1,2} For this reason, the first wearable motherboard is in the Archives of Smithsonian’s National Museum of American History in Washington, DC (see <http://invention.smithsonian.org/centerpieces/inventingourselves/pop-ups/02-04.htm>).

To quote from an early paper on the topic, written in 1999,²

During the latter stages of the research, we coined the name “Wearable Motherboard™” to reflect the accomplishment of the research. Just as chips and other devices can be plugged into a computer motherboard, sensors and other information processing devices can be plugged into the Sensate Liners produced during the course of the research. Therefore, the name “Wearable Motherboard” is apt for the flexible, wearable and comfortable Sensate Liners. The name represents: (1) a natural evolution of the earlier names Sensate Liner and Woven Motherboard; and (2) the expansion of the initial scope and capability of a Sensate Liner targeted for combat casualty care to a much broader concept and spectrum of applications and capabilities.

Indeed, what Cheng and her colleagues have envisioned in their article has been a reality for over a decade; moreover, the design methodology created during the development of the wearable motherboard paradigm has been instantiated to produce application-specific garments for SIDS (sudden infant death syndrome) monitoring, sportswear (vital signs during sports), military personnel (detect shrapnel penetration and

vital signs monitoring), race car drivers (vital signs monitoring at high speeds) and senior citizens, to name a few.

To quote from the first paper on the topic, also written in 1999:¹

By making the sensors detachable from the garment, the versatility of the Sensate Liner has been significantly enhanced. Since shapes and sizes of humans will be different, sensors can be positioned on the right locations for all users and without any constraints being imposed by the Sensate Liner. In essence, the Sensate Liner can be truly “customized.” Moreover, the Sensate Liner can be laundered without any damage to the sensors themselves. In addition to the fiber optic and specialty fibers that serve as sensors and data bus to carry sensory information from the wearer to the monitoring devices, sensors for monitoring the respiration rate (e.g., Respitrace™ sensors) have been integrated into the structure; this illustrates the capability to directly incorporate sensors into the garment.

The research has led to a groundbreaking contribution with enormous implications: The creation of a wearable information infrastructure that has opened up entirely new frontiers in personalized information processing,

AUTHOR RESPONSE

We appreciate Sundaresan Jayaraman's interest on our article and thank him for his comments. We are well aware of his pioneering work, and devices like the Wearable Motherboard and Smart Shirt have been part of the motivation behind our ideas (unfortunately, *IEEE Pervasive Computing* strictly limits the number of citations in department pieces, so there was obviously a lot of related work that we were not able to cite). However, despite the important research that has been carried out, textile wearable computing products are not yet mainstream products; wearable products on the market are mainly electronic devices (such as watches and glasses) that can be attached to the body, so efforts in electronic textiles are still required.

Whereas Jayaraman's work facilitates that "sensors and other information processing devices can be plugged into the Sensate Liners," we propose having the actual sensing structures produced in the textiles using processes that are compatible with the textile industry. Thus, we address sensing concepts, where a sensor can't just be plugged into a textile but where at least the basic sensing elements (such as electrodes) need to be an integral part of the textile, utilizing a large area and the properties of the clothing. The fundamental question that we address is how to produce sensing (not merely communication) structures in the textile in such a way that, with appropriate driver electronics, the structures can support various sensing principles, including capacitive, inductive, as well as biopotential principles.

Our research project addresses the entire chain, from the textile production process through electronics to an operating system abstraction. In summary, whereas Jayaraman's work addressed a textile motherboard into which an electronic sensor could be plugged, we propose generic textile sensing structures that are mass producible with industrial processes, such as weaving and knitting. Additionally, we argue that it's essential to provide meaningful abstraction layers on different levels (for tailors as well as programmers) to enable labor division and eventually an ecosystem of garments, electronic devices, and applications to finally move wearable computing from niche to mainstream. — *Jingyuan Cheng, Paul Lukowicz, and Albrecht Schmidt*

healthcare and telemedicine, and space exploration, to name a few. Until now, it has not been possible to create a personal information processor that was customizable, wearable and comfortable; neither has there been a garment that could be used for unobtrusive monitoring of the vital signs of humans on earth or space such as temperature, heart rate, etc.

Finally, the concept of plug and play was further reinforced in 2003:³

The Smart Shirt is an effective, comfortable, and mobile information infrastructure that can be tailored to the individual's requirements to take advantage of the advancements in telemedicine and information processing. Just as special-purpose chips and processors can be plugged into a computer motherboard to obtain the required information

processing capability, the Smart Shirt is an information infrastructure into which the wearer can "plug in" the desired sensors and devices, thereby creating a system for monitoring vital signs in an efficient and cost-effective manner with the "universal" interface of clothing. This "fabric is the computer" paradigm—exemplified by the Smart Shirt—demonstrates the feasibility of realizing personalized mobile information processing (PMIP) and sets the stage for transforming healthcare in this new millennium.

Thus, the wearable motherboard is a platform that enables true convergence between electronics and textiles. Due to the modularity of the design architecture, the extent and duration of convergence can be controlled by the user. For example, as long as the sensors and processors are plugged into

the wearable motherboard, there is true convergence and the resulting wearable (in the form of clothing) is smart and can perform its intended function—for example, to monitor the wearer's vital signs or other situational awareness data. When this task is completed, the sensors and processors can be unplugged and the garment becomes "dumb" and can be laundered like other clothes. Thus, the usually passive (dumb) textile is temporally transformed into a smart interactive structure and embodies the new paradigm that clothing is an information processing structure that also protects the individual while making him/her fashionable.

Thank you for the opportunity to share with your readers that what Cheng and her colleagues have proposed has been a reality since the mid 1990s, thanks to DARPA funding. ■

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