Wearable Wireless Sensing for Interactive Media

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Sensor technology has evolved with Moore's Law – sensors of all kinds have continued to become much smaller, consume less power, and increase in resolution and/or sensitivity, while the expanding capability of embedded computation enables ever more processing cycles to be devoted to conditioning and interpreting sensor signals. A similar explosion in compact, low-power, high data rate wireless transceivers [1] has enabled untethered sensors to be freely dispersed into locations close to stimuli, rather than relying on remote sensing or wired connections to a central acquisition station. Such advances point towards a world where sensors can be treated as a simple commodity. Rather than omitting sensor subsystems from a cost/complexity viewpoint, it begins to make more sense to just include them (e.g., both by adding more sensor measurements per sensor/processor "cluster" and dropping more of these clusters into the environment) if there is any remote suspicion that they could be needed. This causes a shift in how sensors are used. Rather than relying on only one or two sensors designed a priori to measure particular parameters, many sensors will be used that don't necessarily directly measure the quantity of interest, but allow it and several other parameters to be estimated from the wealth of raw data being produced. This is analogous to vision systems in the large amounts of potentially indirect data being produced, but here the different types of sensors produce measurements of different flavors, as they look at an environment from many different perspectives.

Figure 2: A pair of Expressive Footwear Shoes circa 2000

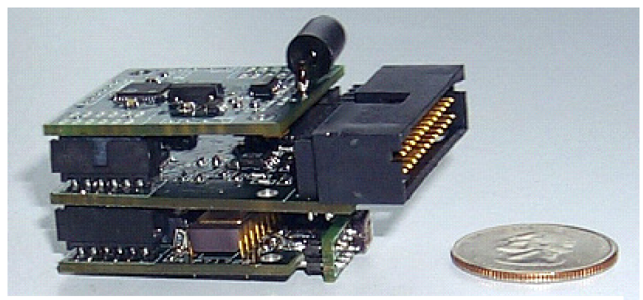

Figure 1: A 3-layer wireless Sensor Stack Module

Several of my research projects at the MIT Media Laboratory have explored the implications of this frontier, especially in wearable sensor suites for human computer interfaces and control of interactive media. Our initial foray into this area was the "Expressive Footwear" project - a pair of shoes (Fig. 1), each instrumented with 16 diverse sensor measurements that were streamed to a remote base station via a wireless data link from each foot. From the initial working prototype in 1997 [2], our design was refined over a couple of cycles during the next few years [3], producing a device that gave dancers the ability to sculpt and control a complex stream of interactive sound and music through their movements. The extreme variety in sensing modality provided by this interface proved to be very useful in detecting and responding to many different kinds of dance movement and gesture. I approached this project from the sensor perspective - knowing nothing about dance, I packed every measurement that would fit onto the foot. As it turns out, all degrees of freedom were useful in mapping content onto the dancer's activity.

The hardware has evolved since into a compact, configurable package of layered sensor modules that we term the "Sensor Stack" [4] (Fig. 2). As each layer encapsulates a dedicated sensing modality (e.g., a 6-axis inertial measurement unit, a tactile interface for gloves or insoles, a sonar proximity sensor), a user can easily configure the cards to sense the desired parameters. A TDMA wireless networking scheme enables data to be rapidly and continually offloaded from an array of Stack devices, as needed for distributing sensing across the body of a user or group of users. The first application of the Stack has been in another shoe, but this one designed to be a wearable gait laboratory [5], developed in collaboration with the Biomotion Laboratory of the Massachusetts General Hospital for diagnosis of gait-related disorders and interactive physical therapy [6]. A collaboration [7] with the National Microelectronics Center (NMRC) in Cork, Ireland is exploring the extreme miniaturization of the Stack's sensor suite by exploiting their expertise in 3D interconnection technologies. We are now beginning a project to apply an array of up to 20 Stack packages to instrument a small dance ensemble who will wear them on their arms and legs, producing massive amounts of data that will must be fused in real time into a relatively small number of high-level descriptive features with which a composer or choreographer can author media content.

Another recent wearable project to which we're applying a similar philosophy is a badge platform that incorporates many different modalities for facilitating interaction between large groups of people. Termed the "UbeR-Badge" [8], this device has been designed to be very flexible in order to host a wide variety of applications in the areas where wearable and social computing converge, from game environments to meetings and conventions. This badge has both RF and IR communication, a 5x9 LED display capable of presenting graphics and scrolling text that users in the vicinity can read, an onboard microphone for 12-bit audio sampling, a 12-bit audio output, a pager motor for vibratory feedback, 3 onboard processors, capacity for up to 256 MB of flash memory, provisions for connecting LCD displays, and connectors that mate into the Stack platform, allowing a variety of different sensors to be integrated. We will be using this device to coordinate interaction and activity in upcoming consortia meetings, where several hundred of our research sponsors and collaborators gather at the Media Lab.

Taking an opposite tack, another project has developed wireless “featherweight” sensing. In particular, we have made a small, very low-cost and extremely low power sensor that sends a very short (50 μs) pulse of 300 MHz RF when it is jerked with an intensity above a preset threshold. These devices are inexpensive enough to be given away with a ticket to a large event (e.g., sports game, convention, or dance club), hence all participants are provided with one “bit” of interaction. By extracting simple statistics from the signals, the amount of activity, tempo, and synchronicity of the participants can be derived, which can be used to drive interactive media that responds to ensemble characteristics [9]. We have tested this system at interactive dance events, where music is generated according to group activity.

Finally, sensors require a power source – as sensor clusters become ubiquitous, frequent battery maintenance becomes impractical, hence careful power management is mandatory, and harvesting energy from the environment is an attractive option if feasible. We are now exploring techniques for dynamically managing a wearable sensor cluster’s resources (e.g., communications bandwidth, power consumption, processing and sensing capability) to maximize performance depending on context (for example, deciding what sensors to sample and how often, what features to calculate, and what data to transmit) [10]. Harvesting parasitic energy from human activity is an option that has a long history [11], from self-powered watches through vibration-to-energy converters for powering implants. Our work in this area has progressed from piezoelectric insoles that extract energy from heel strike and sole bend [12] to buttons that extract enough energy when pressed to wirelessly transmit a unique digital ID code without requiring a battery. Another option is to beam power remotely to wearable sensors. Although inductive charging is standard practice for implantables, we have used this approach for real-time sensing by embedding passive resonant tags into rings that can be wirelessly identified and position-tracked when they approach a reader, producing a simple and nonintrusive hand controller for human-computer interface applications [13].

This work outlined in this abstract has resulted from the labor of many students in the Media Lab’s Responsive Environments Group – consult the cited references and our website (http://www.media.mit.edu/resenv) for more information. We acknowledge the support of the Things That Think Consortium and the other sponsors of the MIT Media Laboratory.

Figure 3: “Featherweight” wireless handheld movement sensors for crowd interaction

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