A Wireless Modular Sensor Architecture and Application in On-Shoe Gait Analysis

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Summary
We have developed a compact wireless modular sensor architecture, which contains a number of circuit boards (panes), currently used in an application for on-shoe gait analysis. Each pane instantiates a major function - inertial sensing, tactile sensing or data collection and transmission. As opposed to similar architectures, this system treats the sensor panes as discrete design objects that have data collection as their primary goal. This architecture has allowed us to develop a shoe-mounted system, which is capable of measuring gait parameters outside of a traditional motion laboratory. The small size of the circuit boards resulted in a small attachment that fits on the back of the shoe, and the integrated wireless transceiver allows the data to be collected continuously and in any environment.

Motivation
The design of the compact wireless modular sensor architecture is motivated by three goals. The first is to encapsulate design knowledge by allowing engineers to build individual panes that reflect a single purpose (data collection/transmission, a type of sensing, etc). This leads directly to the second goal of reducing repeated circuit structure in multiple similar projects. For example, rather than including the same processor and transceiver on each wireless sensor, a single board design incorporating these parts can be used repeatedly. Finally, the third goal of this architecture is to allow for rapid prototyping. The ease of combining and recombining boards makes the testing of various combinations of sensing and processing in a particular application trivial.

The primary difference between this system and other similar architectures is our concentration on the sensor portion of the design, rather than networking concerns. Our system was designed primarily for module to basestation transmission of sensor data for wearable sensors, often requiring real-time updates beyond 100 Hz. Therefore, each pane contains a single sensing goal (inertial, tactile, etc) for which it is optimized. By contrast, the Berkeley Motes¹ allow for expansion, but their current sensor boards tend to contain a collection of useful sensors for a single application, eschewing modularity. The Smart-Its project² is similar to ours in that it is designed around a number of modular functional boards. However, their boards are quite a bit larger (inhibiting many wearable applications) and lean more towards I/O (with RS232 and LCD boards) than data collection.

We first chose to implement this architecture to develop an on-shoe system for monitoring gait. Clinical analysis of walking is traditionally done in one of two ways. The first is visual inspection in a doctor's office, which is solely qualitative. The second involves the use of a motion laboratory. While this is highly accurate, it can be expensive and only captures data about the patient's gait over a distance of a few feet. In either case, the patient is very aware of being tested. Our architecture allows for direct measurement of multiple quantities directly at the point of interest (in this case, the feet). Therefore, we are able to collect data in the subject's natural environment over an extended period of time.

Results
We have designed and built a stable version of the sensor architecture described above. It is based around individual 1.4 inch square boards which are interconnected with two headers totaling 26 (12 + 14) pins. These headers provide both structural strength and electrical connectivity, allowing power, multiplexer lines, interrupts and other signals to flow between the boards. Figure 1 shows some of the current boards, including (counterclockwise from bottom left) a master board consisting of a 22 MIPS processor with 12-bit ADC and 115.2 kbps transceiver, a flat six degree of freedom inertial measurement unit, and a tactile board with inputs for

¹ Project overview at http://webs.cs.berkeley.edu/tos/
² Project overview at http://www.smart-its.org/
force sensitive resistors, piezoelectric sensors, bidirectional bend sensors, and capacitive sensing. A power regulation board is also shown. A sonar rangefinding board is in development. We have built a basestation running a TDMA protocol, which allows us to collect data in real-time from two shoes, each at a rate of 75 Hz. The system, mounted on a shoe, is shown in Figure 2. Preliminary testing has been done with 9 subjects with normal gait, and 1 subject with altered gait due to Parkinson’s disease; the subjects were outfitted with our system on one shoe and the usual Biomotion Lab equipment. Results from 26 trials of 3 of the subjects with normal gait had a mean difference in heel strike time of 87 milliseconds (standard dev, 40 ms). Data collected from the system for several types of gait is shown in Figure 3.

Figure 1. Sensor Hardware

Figure 2. System mounted on a shoe

Figure 3. Sample data from the shoe-based system.