Ultra-Low-Cost Wireless Motion Sensors for Musical Interaction with Very Large Groups

Mark Feldmeier and Joseph A. Paradiso

Responsive Environments Group
MIT Media Laboratory
20 Ames St. E15-351
Cambridge, MA 02139
{geppetto,joep}@media.mit.edu

Abstract. We are developing a set of very low-cost, wireless, wearable sensors that enable a large group of people (e.g., hundreds or thousands) to participate in an interactive musical performance. The sensors themselves are switch-based accelerometers that transmit a narrow RF pulse upon detecting extremes of limb motion. Although we plan to distinguish between sensors on the upper and lower body by using a different carrier frequency and roughly zone the locations of activity through carrier strength, we do not plan to independently ID each performer, but instead measure and react to the characteristics of ensemble behavior. We are currently building this system and starting to develop algorithms that use these data to explore techniques of mapping large-group, real-time musical interaction.

1) Introduction

There are very few systems that enable a large number of participants to collaboratively control a real time, central interaction. Video game systems with up to four and eight controllers exist, but these do not scale up to the necessary level for crowds at a football game, for example. For groups of less than a hundred participants, there exist fixed systems such as game show audience pushbuttons that are located in the armrests of the audience's chairs. These can be depressed for simple voting on outcomes. But, for participants in numbers over a hundred, hardwired solutions become costly, and do not allow the participants to be mobile. Some systems enable many participants to become engaged via wireless PDA's [1] or even cellphones, but these are quite costly and generally not entirely real time. Likewise, multiplayer gaming systems exist on the internet that can accommodate players in the thousands, but here the interaction is generally not even close to real time. Systems that look for cues from infrared cameras [2], microphones [3], or capacitive sensors [4] can gather information over a large mobile audience, but they do not lend themselves to direct control by an audience member. The participant has no clear action that will dictate a desired response. For this to happen, there must be an effective way of measuring a particular action amongst all participants. This has been done via machine vision (witness Loren Carpenter's red-green voting paddles [5] and Scheirer and Picard's glowing Galvactivator skin-resistance detectors [6]), but they require a line-of-sight from camera to participant and are susceptible to illumination effects and background clutter. In general, making these types of measurements using non-contact methods such as machine vision or machine listening is not as accurate as direct methods such as wearable or handheld sensors that transmit directly via an RF link. One example of such a wearable device is the Sophisticated Soiree installation [7] at Ars Electronica 2001, where up to 64 participants were given wireless heart rate sensors that were used to control a musical stream for an experiment in large-group biofeedback. People don't have direct control over sympathetic responses such as heart rate and skin resistance, however - another strategy is to give them wireless devices that respond to immediate kinetic input that provides very causal control. For such a system to work, each participant must be supplied with a sensor that has a consistent response given a particular input. For such a controller to be viable on scales of hundreds to thousands of participants, they must be inexpensive, wireless, intuitive to use, and operable for many hours (if not weeks) without draining its battery. In an effort to achieve these goals the devices described below are being developed at the M.I.T. Media Laboratory.

2) The Wireless Sensor

The controllers are part of a system used to measure the activity level of a crowd. They are small, inexpensive, wireless transmitters that send a short burst of RF energy whenever they sense acceleration greater than a predetermined level. These transmitters are either worn or held by a participant, and are triggered by motion. We currently envision them to be attached to the limbs, as in Figure 1. Both the strength and duration of the RF burst are kept to a minimum in order to make collection of information possible. The short transmission radius creates zones of interaction around the receiving antenna, and the short transmission time reduces the probability of collision between transmissions. In this way, the pulses in a particular area can be summed to give a sense of the activity level of participants in that area, while still receiving each participant’s action as a distinct event.

Ten prototypes of these controllers have been assembled and tested. In its current form, the controller consists of a trigger, debouncing circuitry, and an RF transmitter. The schematic is shown in Figure 2, and a photograph of our prototype device is shown in Figure 3. They currently measure 9cm x 2cm x 1cm and weigh 5g. These dimensions will be significantly reduced in the next phase of production when double sided boards and surface mount components are used.

The trigger is a piezoelectric film sensor from Measurement Specialties Inc. This PVDF film is weighted to give the desired level of sensitivity. Whenever the controller is accelerated past this sensitivity threshold; either by shaking the controller in one’s hand or stomping with the controller attached to one’s shoe, the piezo triggers the 74HC221 dual CMOS timer. The first half of this timer produces a 100ms pulse to eliminate double triggering due to piezo film ring down, and the second half produces a 50μs pulse that activates the transmitter. The Ming TX-99 V3.0 is used as the transmitter. It operates at 300MHz and has an effective transmission radius of 6 meters when operated at 3 volts.

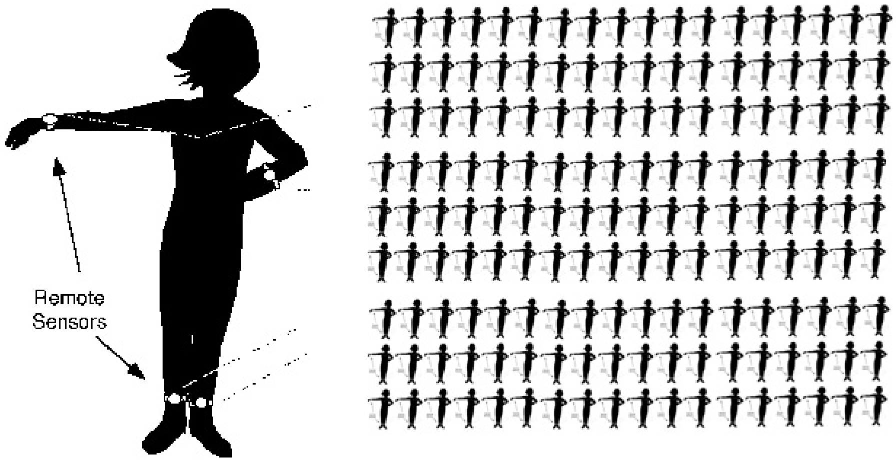

Fig. 1. Wearable sensor packages at each limb for individual and large ensemble

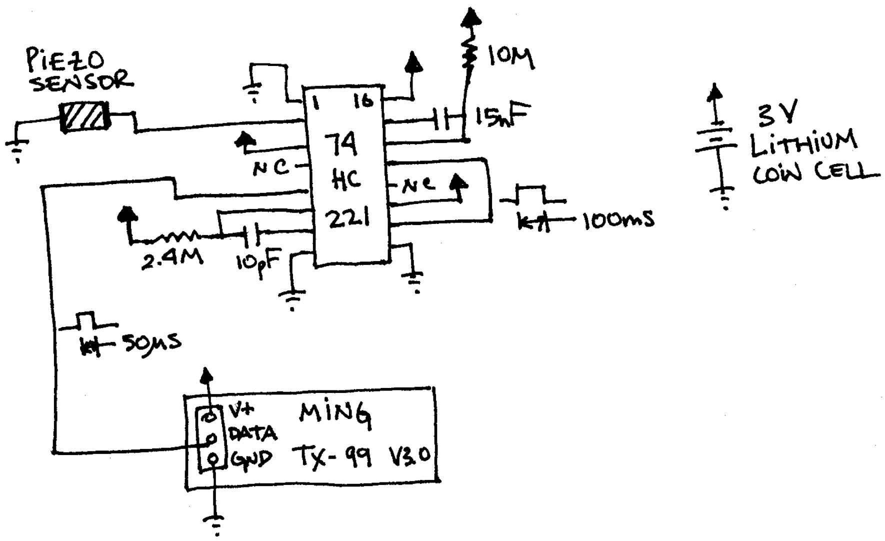

Fig. 2. Schematic of basic wireless inertial sensor unit

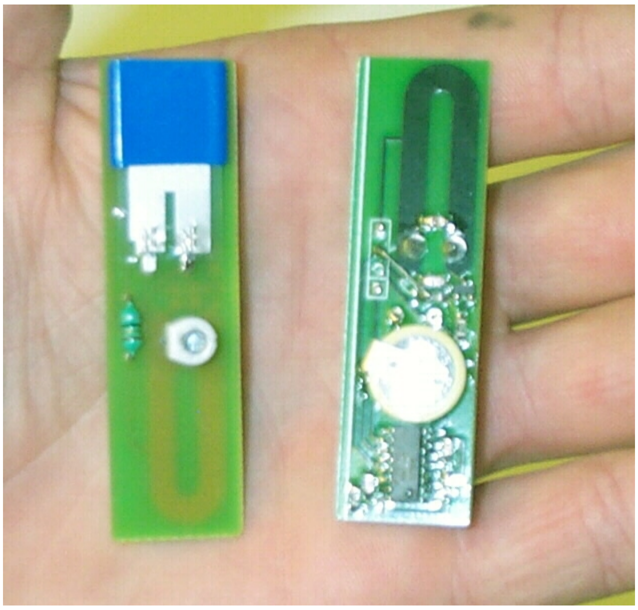

Fig. 3. Working Prototype of Wearable Wireless Sensor Unit, front and back views

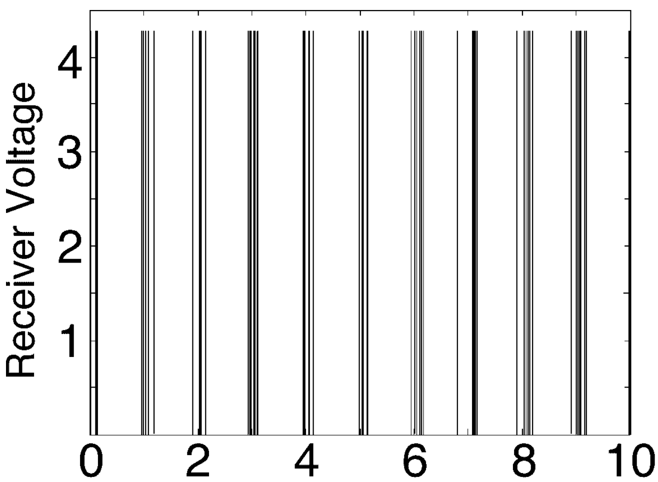

Fig. 4. Signal at Receiver for 7 people wearing these sensors on their wrist while attempting to clap in unison

The power for the controller comes from a single 3 volt lithium coin cell 12.5mm in diameter and 2.5mm in width. The circuit consumes less than .01μA in standby, and an average of a few microamps during the 100ms debouncing operation. At the rate of two transmissions per second, the battery would last for a month of continuous usage, and indefinitely with no usage (the lithium battery shelf life is approximately ten years, making the controller a reusable item. The current prototypes are still running after three months of intermittent usage).

The cost of the prototypes is currently dominated by the Ming transmitter. For quantities of ten, the price breakdown is as follows:

Part	Cost ($)
Transmitter	10.00
Battery	1.73
Piezo	.73
74HC221	.88
TOTAL	**13.34**

For larger quantities, the cost of battery, piezo, and timer will be approximately halved. The transmitter will be custom designed and produced, reducing its cost to that of a transistor and few passive components. The total cost will then be under three dollars per controller for parts, making it viable as a giveaway item. The basestations will be somewhat more expensive, of course, but as the signal processing for these systems should be fairly minimal, we assume that the cost of the base station array will be dominated by the host computer.

In many applications it will be appropriate to have zones of interaction. In these cases, the controller takes on different actions, or changes character depending upon where it is located. Zoning also allows for competition amongst users in different zones. The short radius of transmission allows for multiple zones to be established, with zone diameter being set by the cut off level on received transmission strength, while all transmissions above that strength still have the same voting power. Since there is no ID and all pulses are of the same width, the system gives equal weighting to all votes. For interactions where this is not ideal, the participants can be made aware of the location of the receiver, and voting strength can be determined by received signal strength. Noise immunity is gained by the consistency of the pulse width. The received signal can be processed to eliminate any pulses that are either shorter or longer than 50μs. The probability of any two pulses lining up within a zone containing several dozen people is very low, even when they're trying to synchronize to beats of a musical stream. Figure 4 shows the response of a receiver to 7 such sensors for people trying to clap in unison - the correlation on the beats is obvious, but the pulses are far from lining up with one another.

3) Application and Analysis

As we are currently building a large-scale system with these sensors, we are only beginning to address the crucial issues of effective mappings of collective gesture in large groups. We will explore algorithms that produce musical streams that encourage patterns of motion to develop across large groups of people, and slowly evolve them based on smaller-scale features that are detected, encouraging them to propagate into the larger group. Likewise, with our zoned system, we can encourage and propagate local variations in more global activity patterns. We expect that our system will have applications in many types of group activities, from interactive dance "raves" through group aerobics and exercise. Although the noise sensitivity of our system will be considerable as there is no coding of the sensor signal apart from a fixed pulse-width, the sensor transmission strength within a bounded zone should be sufficient to set the receiver's amplitude threshold above common ambient interference. Although signal coding and two-way communication could effectively reduce interference, we have elected not to go this route to keep our system extremely low cost, low latency, and low power. Similarly, we feel that missing occasional signals in large groups will be significantly less critical than for smaller groups.

4) Conclusions

One of the big unsolved problems in interactive music and entertainment is how to make responsive environments reflect and react to the collective activity of large groups. It's not clear, in fact, that any meaningful interactive content can be done on this scale (e.g., the individual feels some sense of causality while the music sounds good to the entire group), although the possibilities at this frontier are indeed tantalizing. We are thus building a research tool to explore the development of meaningful content mapping algorithms with such large crowds.

5) References

[1] Falk, J., Ljungstrand, Pl, Bjork, S., and Hansson, R., "Pirates: Proximity-Triggered Interaction in a Multi-Player Game," in the Proc. of the CHI 01 Conference on Human Factors in Computing Systems, Extended Abstracts, ACM Press, New York, 2001, pp. 119-120.

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