2011 International Conference on Body Sensor Networks

# Wireless Hand Gesture Capture Through Wearable Passive Tag Sensing

Rachel Bainbridge
Responsive Environments Group
MIT Media Laboratory
Cambridge, MA –USA-
e-mail: ithron@mit.edu

Joseph A. Paradiso
Responsive Environments Group
MIT Media Laboratory
Cambridge, MA –USA-
e-mail: joep@media.mit.edu

*Abstract*— **For wearable computing to become more widely accepted, the associated Human-Computer Interface must move past today's keyboard, keypad, touch screen, or other bulky hand-held interfaces to allow a user to specify input through their fingers without taking their eyes and attention off their immediate focus. Accordingly, we have developed a wearable system to track hand gestures with passive RFID sensor tags. This system is composed of an ultra-high frequency (UHF) reader and small, passive, finger-worn tags powered by transmit RF energy, each equipped with a variety of sensors that could be used to detect gestures. The primary physical goals of the system were to be comfortable and wearable without interfering with other everyday activities while tracking particular hand movements that could be used to control a wearable computer or aid in interaction with ubiquitous or other wearable devices. This paper first introduces our hardware, then gives some example user interface implementations, such as a mouse scrolled by hand position and a click specified by finger proximity, entering input by touching fingers, setting options when moving the hand to a particular spot of the user's apparel labeled with a passive RFID tag, and otherwise mapping control onto motion of the hand, arm, and fingers. The overall system was fully functional, but as this is an early implementation, it was still very much limited by transmit power and antenna efficiency, due to the constraints on the size of the passive tags. Means of scaling to lower power and smaller size are suggested.**

***Keywords- HCI; wireless finger tracker; wearable computing; passive sensing; RFID***

## I. INTRODUCTION

Today's common mobile computing environment will naturally evolve into a truly immersive wearable system, where it will become inconvenient and impractical to employ standard human computer interfaces (HCI's). Especially when interacting with a wearable display, holding or manipulating a presently familiar HCI device will become increasingly impractical. While it is important to keep a user's hands and fingers as free from encumbrance as possible, finger manipulation will continue to be crucial, as our HCI bandwidth is highest there due to finger dexterity. Accordingly, we seek to track the movements of fingers and hands while keeping them free of encumbrance or excessive postural constraint. This goal led to the project described in this paper, which monitors finger movement and contact using a small wearable and portable system composed of an RFID reader and small, passive finger-mounted tags. We describe a working prototype of this system, and present an initial evaluation of its utility through a series of preliminary user studies.

## II. PRIOR WORK

There already exist many methods of hand gesture identification and tracking, as summarized below. They tend to all involve constraints that make their use in a commonplace wearable system impractical.

Several recent projects (e.g., [1]) involve the use of wearable machine vision to determine hand/finger gestures of various sorts. These methods are limited by the line of sight of the associated camera, hence have limitations on the sensitive region. The hands need to be in the field of view, which generally means that gesture needs to happen in the area in front of the user. This can tire the user and isn't always practical (e.g., when standing in a crowded train, walking, etc.). Although one could think of a sleeve-mounted camera, it would have difficulties with the fingers occluding one another. As these systems use computer vision, they can also be fragile with varying lighting conditions, as well as requiring the user to wear targets on the fingers (colored bands in the case of [1]).

Other previous projects have striven to track hand movement and gestures with other means to create novel and natural ways for users to interact with wearable technology. Perhaps the best-known products in this space are wearable and chordic keyboards, such as the Twiddler (http://www.handykey.com/), and various types of datagloves [2]. Although users have achieved a high degree of fluency with the Twiddler [3], it is a relatively large object that needs to be attached to the palm with a strap, hence limits the use of the hand. Datagloves of various sorts have been used for over two decades, especially in virtual reality applications. Some gloves (e.g. Sonami's Lady's Glove [4]) use a magnet on the thumb and hall sensors on the fingers to sense finger-to-thumb gesture, as we exploit in this project. As these cover the entire hand, they are difficult to wear for extended periods and in all circumstances, and although they provide ample data on finger position, they significantly encumber the fingers. A somewhat recent project at Keio University [5] created a finger-gesture "remote control" for managing multiple electronic devices in a room with gesture, the same way a remote control might with buttons. This device included an accelerometer, a bend sensor and a push button, as well as an infrared LED to allow the device to communicate to a server that could then communicate to the appliances. It was wired, however, and occupied much of the index finger.

978-0-7695-4431-1/11 $26.00 © 2011 IEEE
DOI 10.1109/BSN.2011.42

Products have been marketed for a decade or so now that use ultrasound to track a small active sonar ring on the finger, generally mapped as a mouse controller. One recent reincarnation is the ”MagicMouse” from WPI [6]. Although this product has been reinvented several times, it’s never caught on because of problems related to accuracy, occlusion, lack of a clear market advantage in its targeted niche (replacement of the standard mouse), and need of wearing a fairly bulky active sonar transmitter on the finger. A couple of recent websites [7,8] also point to what appear to be battery-powered ring-based controllers, but there is very little information provided, hence it’s not clear what these devices actually do, how they work, and whether they are actual products or just conceptions – they do not appear to be generic free-gesture finger interfaces such as we have realized in our work.

The Nenya project [9] from Nokia Research is a ring controller that employs permanent magnets embedded into a standard ring that are tracked by a magnetometer at the wrist. This interesting implementation can determine the twist of the ring, and has some ability to determine finger orientation relative to the wrist sensor. This implementation requires strong magnets in the ring, however, and more than one finger isn’t possible because of ambiguities and mutual mechanical coupling, plus there is no intrinsic “click” gesture.

A pioneering project in this area was implemented in 1997 by Masaaki Fukimoto at NTT Human Interface Laboratories [10]. Fingertip “typing” was sensed by accelerometers and then transmitted capacitively using the body as part of the circuit [11]. Although this project was groundbreaking in many ways, the finger rings required batteries and the electric field communication reliability was questionable. Paradiso et al [12] demonstrated simple tracking of fingers with chipless, passive magnetic ring tags a decade ago, but these only detected AC field coupling in proximity to a large static reader coil. Other projects, again dating back a decade, used hand or sleeve-mounted inductive RFID readers to detect particular objects being held (e.g., [13,14]), but these weren’t concerned with sensing gesture.

Several other projects have exploited finger tapping for useful gestural interactions. A 2007 study at the University of Tokyo [15] indicated that analysis of signals produced from accelerometers on rings could determine what part of the finger was being contacted. Skinput, a recent project by CMU and Microsoft Research, has interpreted vibrations picked up on the arm by an array of contact acoustic pickups to sense when different parts of the hand or arm are being touched [16]. Although this is a fascinating approach, this method requires a large cuff to be in contact with the upper arm and measures only finger contact, not gesture. Other work has exploited EMG sensing of arm muscles to determine finger pointing [17], but these techniques require an array of contact electrodes to be applied to the skin, typically at the forearm – in addition to being uncomfortable, such EMG techniques are known to have problems with robustness (e.g., electrodes can shift, and signals for similar movements can vary).

We see an opportunity for a new class of wearable user interface, based around recent advances in RFID sensing, which potentially allows the passive sensors to become quite small, perhaps approaching the size of rings that could be placed inconspicuously around the upper finger joints and work with a reader mounted near the sleeve. In this paper, we describe what we believe to be the first implementation of such a system.

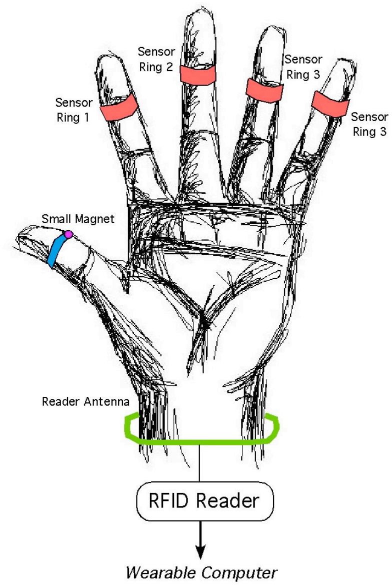


Figure 1. System Configuration.

## III. SYSTEM IMPLEMENTATION

Figure 1 shows the basic ideal configuration of our system, and Figure 2 shows the actual working prototype that we built and tested. We initially tried using passive, magnetically-coupled, near-field RFID transponders, since they are extremely simple, magnetic fields freely propagate through the human body, and the tags can to some extent indicate their distance from the reader by their signal strength, as in [12]. Although this approach may prove practical with further development, we abandoned it for a number of reasons, such as: the signal strength of tag can also be tied to its orientation, the tags and reader tended to be too large, the reader was not fast enough, and the range of the reader was too limited. While searching through possible solutions, it was found that the UHF band (860MHz to 960MHz) would allow for a reduction in tag size and also in reader size, while still penetrating the human body to some extent [18], avoiding extreme occlusion problems. Also it was found that microprocessor-equipped UHF tags, the WISP project [19] from Intel Research in particular, might also provide a viable solution to our desire to track the position of a finger - especially since the WISP already incorporated an accelerometer on the tag, could accommodate other sensor signals, and required no power source except for the reader itself.

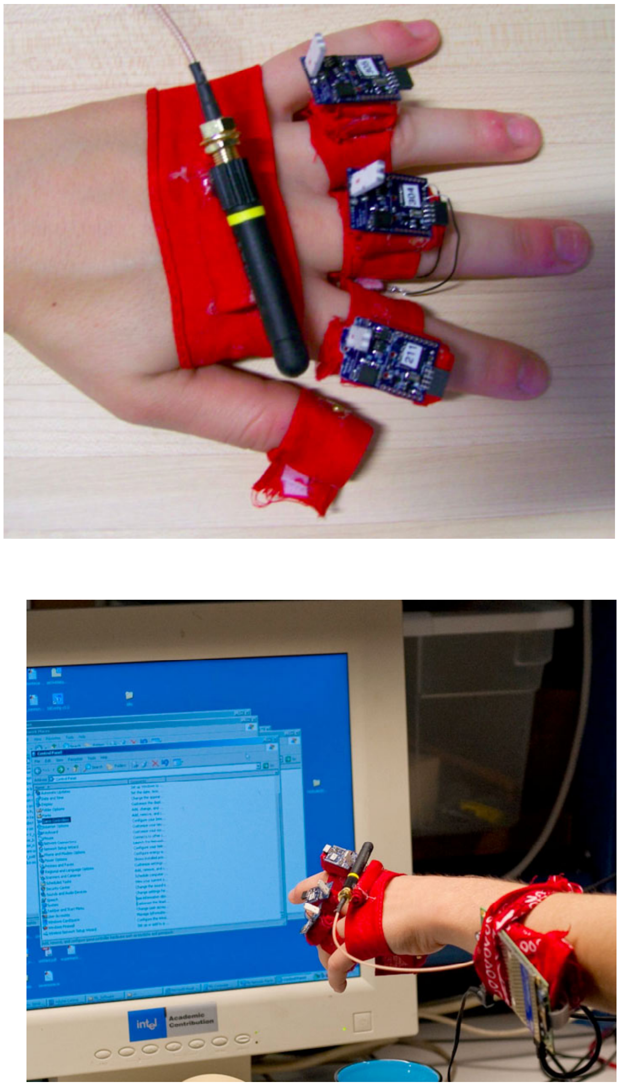

Figure 2. Our prototype system on a user's hand (top) during tests (bottom).

The Intel WISP tag that we employed is small (and can grow smaller with better electronics integration), 1.5 cm x 2.5 cm (aside from its large standard dipole antenna), hence it can easily fit on a finger. As the dipole antenna is around 16-cm in length, it was a hindrance to finger motion and couldn't be used. However, it was within the scope of this project to reduce the size of the antenna while still maintaining the needed range, especially as we only needed sensitivity out to a few inches or so. Since the WISPs and reader will be in close proximity to the hand and wrist, the effect of the body on the fields and transmissions must be taken in to account. Human tissue is a lossy medium that can greatly alter the parameters of an antenna, which are usually characterized in free space.

Several tag antennas were tried (meandered dipole antennas, chip antennas, nearfield loops) – details are given in [20]. In our final tests, although better RF performance could be gleaned from the meandered dipoles, we used the chip antennas (from Johanson Technology), as they were significantly smaller and still gave satisfactory operation over the short range used here. We employed the Mercury M5e reader from ThingMagic with a ¼ -wave monopole whip antenna driven at 916 MHz over 7" of cable – this allowed us to mount the whip antenna at the wrist and the reader electronics back up on the arm, avoiding encumbering the hand while incurring under 4% efficiency loss from the cable.

A user's hand outfit with the tags and reader antenna used in our tests is shown in Figure 2. Although, in principle, fully outfit WISP tags could be placed on all fingers (per Fig. 1), we equipped only three fingers with tags – the index finger, the middle finger and the ring finger. The index finger included a 3-axis accelerometer, enabling full tilt and motion dynamics sensing, while the other two fingers had only a small magnetic reed switch, which could detect contact proximity of a small magnet fixed to the thumb. Velcro attachments enabled the entire rig to be put on within seconds. As elaborated later, this is very much a first prototype using off-the-shelf modules – dedicated design optimization, and integration should be able to shrink the system significantly. In addition to the WISPs, a standard 916 MHz passive RFID tag was mounted at the user's belt – as this tag was read when the hand was near the waist, it provided an easy and reliable means of recognizing a particular hand position (hand at stomach), which we implemented as a "mode change" switch in our test software (a similar implementation of labeling body locations with passive RFID tags was explored in [21]). Placing such simple proximity-read RFID tags at various parts of the body can reliably detect particular physical posture, as has been pursued less precisely by integrating accelerometers on mobile phones, for example, in [22].

In our tests, a simple C# application, detailed in [20], analyzed the received tag data on a PC laptop, detected particular gestures, and drove mouse operations on a standard Windows GUI. This GUI interface was put together only to enable a preliminary test of this interface – in actual practice, the gestures parsed by this system should be more appropriate to the wearable/mobile applications to which it is suited. Raw accelerometer data was processed through a deadzone filter to cut drift due to baseline noise, then run through a zero-velocity filter to chase offset drift. Accelerometer signals were then analyzed to determine 2-axis index finger tilt for x/y mouse scrolling as well as index finger taps for selection operations. Bringing the magnetized thumb against the middle finger served as a mouse click – placing the thumb against the ring finger toggled mouse scrolling on and off. When mouse scrolling was enabled, once the index finger was tilted off vertical beyond the ~20° deadzone, the mouse scrolled with a velocity proportional to finger inclination and 2-axis scroll direction determined directly by the continuous tilt vector. When scrolling was disabled, index finger taps against various surfaces could be easily detected via a binary threshold on the accelerometer signals, as the acceleration signature has a canonical bipolar peak [20].

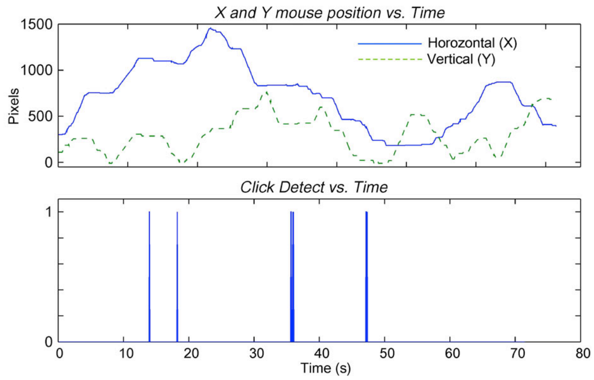


Figure 3. Processed mouse tracking coordinates (top) and click data (bottom) vs. time for a user interacting with the GUI application.

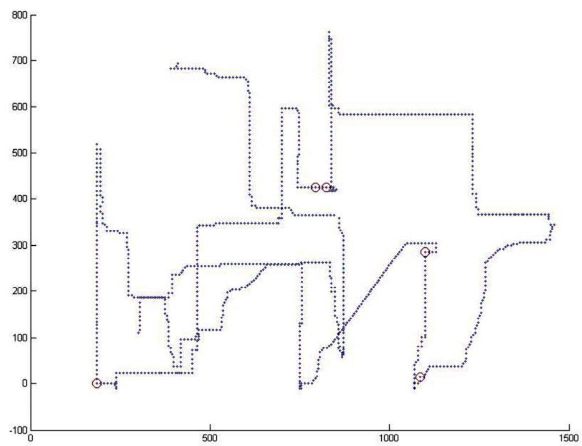


Figure 4. Actual mouse trace (plotted in pixels) for a user manipulating their index finger to scroll around the GUI screen. Clicks are denoted by circles. This is an XY plot of the data shown in Figure 3.

## IV. TEST RESULTS

Data from a user interacting with the system is presented in Figures 3 and 4. In Figure 3, the accelerometer data is seen to resolve well into tilt (the effect of the baseline deadbands are obvious), and the finger-to-thumb "click" gestures are easily resolved without additional processing beyond simple temporal debouncing. The update rates that we achieved with the current geometry varied from 10-40 Hz depending on the bit-error rate encountered [20], with the lower rates seen mainly in the ring and middle fingers when they were occluded by the hand and significant RF loss was encountered. Figure 4 shows a simple XY trace of a user's activity when using their index finger to scroll around the screen together with finger-to-thumb clicks.

This system, running with the simple GUI application described above, was tested by six different users. All of the users were students at our institute with a background in computers and engineering. They were instructed on how to put on the tags and reader, connect to and calibrate the system, and operate the system in different modes. On average they used the system for twenty minutes to a half hour. Once they were wearing the system, they were given an explanation of how the gestures were recognized for the mode they were operating in, and given a few minutes to practice with the system before being asked to try to complete a task, such as type a word with a scroll and select interface or click a button. The system was not specially calibrated to them, aside from the startup calibration for gravity and initial hand tilt.

Despite the fact that the physical design of this system is far from perfected, users rated it a 7 out of 10 in terms of comfortableness, and although they could put the rig on in under a minute wanted even faster set up. These users were able to scroll and select successfully, but could require between 30 seconds and a minute to click a typical button on 1280 x 1024 display, hence rated the pointing efficiency a 6 out of 10 in difficulty. This improves with practice, however – the primary investigator on this task, having spent roughly 10 hours with this system, was able to operate it much better, and began to approach interaction speeds compatible with mousing. Again, this desktop GUI test application was put together only for a quick test of system utility – a more relevant evaluation would implement an interface application more appropriate for the wearable, hands-free niche the system is aimed towards and not just map simple tilt to mouse scrolling.

## V. CONCLUSIONS

We have built and tested, to our knowledge, the first implementation of an HCI finger gesture tracking system built from passive RFID tags. Our system, however, is early, and can be improved in many ways. Most issues that we faced in fielding this system were related to power needed by the small passive tags and the implementation with available off-the-shelf components. The WISPs, for example, while quickly enabling this project, leverage a general-purpose, albeit low power microprocessor (the MPS 430-2132 taking 200 μA/MIP), and the accelerometer (an ADXL330) needs 180 μA. An ASIC customized to this task would be much more power efficient (e.g., state machines used in RFID tags can consume circa 2 orders of magnitude less power [23]), plus a more energy-conscious accelerometer design (e.g., [24]) can take orders of magnitude less current. Better antenna design and matching (e.g., our chip antennas are monopoles, wheras the WISPs were set up for a dipole) should also help to shrink the tag form factor to the point where it begins to approach a standard ring. The 916 MHz frequency used here was also chosen because of the RFID-based hardware that we had available for our tests – a lower frequency will exhibit less absorption by the hand when its between the rings and the reader (our data rate would be seen to drop significantly if the middle and ring fingers were bent down below the hand). Note that a WISP is unnecessary for fingers that do not need pointing requirements – having the reed switch disable the antenna or otherwise change the coded response of a standard RFID tag would be adequate for simple clicking.

The power requirements, antenna constraints, and signal loss effects across the hand resulted in our employing a significantly powerful reader in this implementation – the M5e provides 30 dBm of RF output, but requires on average 4 Watts of power (meaning that it would last circa 12 hours on a standard laptop battery). A more efficient and better optimized system per the above prescription could lead toward a lower power reader with the antenna mounted above the hand (perhaps integrated into the sleeve) and tags integrated into simple rings worn for example, at the upper knuckles, as in our motivating vision of Fig. 1.

The actual system implementation could also improve by being better informed by particular applications. For example, specific hand gestures can be identified that are relevant to the desired functions (not just tilt-into-scroll and touch-into-click, as in our tests), and full-up sensing tags can be applied to all four fingers instead of just the three implemented in our tests.

## ACKNOWLEDGMENT

We thank Yael McGuire of ThingMagic for his RFID advice and technical support, as well as Josh Smith, Jeff Braun, and the WISP team at Intel Seattle for giving us the WISP system and helping us get going with it. We thank our colleagues in the Responsive Environments Group for all their help, especially Laurel Pardue, Matt Aldrich, Mark Feldmeier, Nan-Wei Gong, and Gershon Dublon. This work was supported by the Media Lab's sponsors and industrial consortia.

## REFERENCES

[1] P. Mistry, P. Maes, L. Chang, "WUW - Wear Ur World - A Wearable Gestural Interface," In the CHI '09 extended abstracts, Boston, MA. 2009.

[2] D. Zeltzer D. Sturman, "A survey of glove-based input," in IEEE Computer Graphics and Applications, Volume 14, pp. 30–39, 1994.

[3] T. Starner et Al., K. Lyons, "Twiddler typing: one-handed chording text entry for mobile phones," in Proc. of CHI 04, Vienna Austria, 2004.

[4] J. Paradiso, Electronic music: New ways to play, IEEE Spectrum, pages 18–30, December 1997.

[5] M. Yasumura K. Tsukada, "Ubi-finger: Gesture input device for mobile use," in Proceedings of APCHI 2002, Vol. 1, pp. 388–400 (2002).

[6] White, C, "Magicmouse puts 3D control on your finger," Gizmodo, May 2007. See: http://gizmodo.com/262453/magicmouse-puts-3d-control-on-your-finger.

[7] http://www.hybratech.com/orb.php

[8] http://www.ringbow.com/

[9] Ashbrook, D., Baudisch, P., White, S., "Nenya: Subtle and Eyes-Free Mobile Input with a Magnetically-Tracked Finger Ring," to appear in Proc. of CHI 2011, Vancouver B.C., May 7-12, 2011.

[10] Y. Tonomura M. Fukumoto, "Body coupled fingering: Wireless wearable keyboard.," Proc CHI'97, Atlanta Georgia, pages 147–154, 1997.

[11] T. Zimmerman, "Personal area networks: Near-field intrabody communication," In IBM Systems Journal, Volume 35, 1996.

[12] J. Paradiso, L. Pardue, K. Hsiao, and A. Benbasat, "Electromagnetic tagging for electronic music interfaces," in Journal of New Music Research, Volume 32, pages 395–409, 2003.

[13] C. Merz A. Schmidt, H. Gellersen, "Enabling implicit human computer interaction - a wearable RFID-tag reader," in the Fourth International Symposium on Wearable Computers (ISWC'00) Atlanta, GA, pages 193–194, 2000.

[14] A. Feldman, E. M. Taoa, S. Sadi, P. Maes, and C. Schmandt, "Reachmedia: On-the-move interaction with everyday objects," In ISWC'05: 9th International Symposium on Wearable Computing, pages 52– 59, 2005.

[15] H. Shinoda T. Iwamoto, "Finger ring tactile interface based on propagating elastic waves on human fingers," Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pages 145–150, 2007.

[16] Harrison, C., Tan, D. Morris, D. 2010, "Skinput: Appropriating the Body as an Input Surface," In Proceedings of CHI 2010 (Atlanta, Georgia, April 10 - 15, 2010).

[17] T.S. Saponas, D.S. Tan, D. Morris, R. Balakrishnan, "Demonstrating the Feasibility of Using Forearm Electromyography for Muscle-Computer Interfaces," CHI 2008 Conference on Human Factors in Computing Systems, pp. 515-524

[18] W. G. Scanlon and N. E. Evans, "Numerical analysis of bodyworn UHF antenna systems," Electronics & Communication Engineering Journal, April 2001, pp. 53-64.

[19] J. R. Smith, A. Sample, P. Powledge, A. Mamishev, and S. Roy, "A wirelessly powered platform for sensing and computation," in Ubicomp 2006: Eighth International Conference on Ubiquitous Computing, pages 495–506, Orange County, Calif., 17–21 September 2006.

[20] R. Bainbridge, HCI Gesture Tracking Using Wearable Passive Tags, M.Eng. Thesis, MIT EECS Department, September 2010.

[21] Headon and Coulouris, "Supporting gestural input for users on the move," in Proc. EuroWearable '03.

[22] J. Angesleva et al., "Body mnemonics: Portable device interaction design concept," In UIST'03, Vancouver, Canada, November 2003.

[23] Finkenzeller, K., RFID Handbook, Second Edition, Wiley, 2003.

[24] M. Feldmeier and J.A. Paradiso, "Personalized HVAC Control System," in the Proc. of the Internet of Things Conference, Tokyo Japan, December 2010.