Things that Hover: Interaction with Tiny Battery-less Robots on Desktop

Takashi Miyaki
Karlsruhe Institute of Technology
TecO, Vincenz-Priessnitz-Str. 3, 76131 Karlsruhe, Germany
miyaki@acm.org

Yong Ding
Karlsruhe Institute of Technology
TecO, Vincenz-Priessnitz-Str. 3, 76131 Karlsruhe, Germany
ding@teco.edu

Behnam Banitalebi
Karlsruhe Institute of Technology
TecO, Vincenz-Priessnitz-Str. 3, 76131 Karlsruhe, Germany
behnam@teco.edu

Michael Beigl
Karlsruhe Institute of Technology
TecO, Vincenz-Priessnitz-Str. 3, 76131 Karlsruhe, Germany
michael@teco.edu

CHI 2011, May 7–12, 2011, Vancouver, BC, Canada.
ACM 978-1-4503-0268-5/11/05.

Abstract

This paper presents computationally and physically augmented desktop objects - "Things that hover" - that is capable of moving autonomously on desktop, and discusses about technical mechanisms, future possible interaction styles and applications based on this architecture. A goal of the design is to create self-moving robotic modules on top of a flat surface. Integrating lightweight piezoelectric air-blow actuators and contact-less power providing technology from desktop surface, tiny robots can hover and control the direction of movement without any battery, which illustrates that our approach is practically feasible.

Keywords

Interactive devices, piezo actuator, microblower, surface computing, hovercraft

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: User interfaces

General Terms

Experimentation

Introduction

In our daily life, physical interactions with surrounding objects have important meanings. Not only through visual or audible information but also tactile information, people can sense the real world. We can touch to feel tactile sensation from real objects, and also objects in real world can be movable. Many efforts on tangible user interface approaches have been done in the past decade. Tangible user interface has enabled users to interact with real objects that are augmented by or tightly bound to digital information.

One of the limitations of current tangible user interface is lack of mobility of real objects. Once an object is thrown into the real world, its position cannot be easily changed any more. This is because a moving cost of real object body, which has a mass, is so much higher than that of digital information displayed on monitor. On the surface of real world, friction is everywhere. However people are living in not only static situation, but dynamically changing situation in which interaction target will move.

Therefore, creating desktop objects, which move freely on the real surfaces, is a big challenge. For physical and virtual world integration, potentially simple mechanism is needed. That will extend only "touchable" object to self-movable object which can move as reaction against human action. We call this dual physical interactivity as "two-way interaction" in this paper.

In this paper, we propose new actuation architecture to bring this two-way physical interaction into desktop environment. Combining piezoelectric ceramic-based actuator and 2D power sheet, tiny battery-less robots, which hover over desktop surface, can be constructible in feasible setup as shown in Figure 1. It also has a potential of creating omni-directional movement for small desktop object. The authors show mechanism of controlling direction of movement using multiple actuators with differential actuation strength.

This architecture enhances cross border interaction between physical and digital world on desktop environment, which is potentially simple and energy efficient. We introduce initial implementation in following sections.

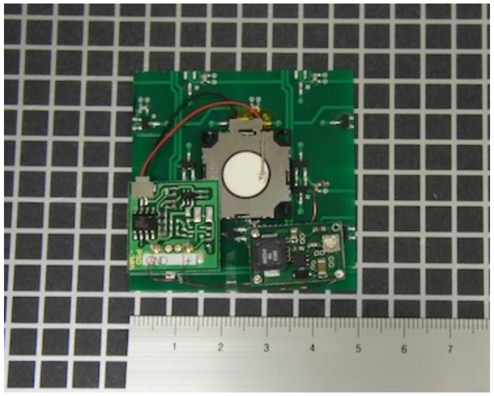

Figure 1: A Things that Hover node: microblower, rectifier, DC/DC and Amplifier are combined with small body (50 x 50 mm)

Related work

Tangible user interface:
A number of efforts on tangible user interface research have used physical objects as a means of human computer interactions [3, 20, 1, 6]. "Composition on the Table" [7] is a series of installations by Toshio Iwai which is based on Mixed Reality style physical interactions. DataTiles [17] combined digital and physical user interfaces in real objects.

One of important challenges in tangible interface is using kinetic movement of objects. Especially controlling movement of small objects on the top of desktop surface is difficult problem because of its actuation mechanisms.

There exist several types of approach to conquer this problem. One approach is using robot that has DC motors. curlybot [5] is an early example of a robot which runs on desktop and interact with users.

The other approach is the method using electromagnetic actuators embedded under the table [14, 21]. Reznik proposed actuation method based on a single, horizontally vibrating plate [18].

However these approaches have problems in its size or installation cost. Robots with DC motors tend to be bigger to get omnidirectional movement and how to get power is also another big problem. For electromagnetic or vibration based actuation, actuator embedded table is costly and has limitations to be used in home environment.

Robots:
Several interface systems have used a desktop small robot or kinetic movement. curlyBot [5] is an early example of desktop robot. iRobot Roomba which is based on simple algorithms [2] have realized most successful use of robots in real world applications for living space. Comparing to these conventional robots, our method reduces mechanical complexity in minimum.

Kinetic interaction:
Several researches have been conducted on kinetic interaction [15]. Lumen [16] is a self-deformable display device. People can touch and feel the volume through the device as well as visually changing color information. Kinetic tiles [9] is another example of modular blocks which acts as kinetic surface display.

Not only discrete mechanical movement, continuously adjustable movement has been also investigated. Inflatable mouse [10] is volume-adjustable mouse along with pressure sensitive feedback. People can physically feel the device lively such as living things. In our Things that Hover system, once the object hovers, friction is suddenly disappeared and that enables object move freely. From our casual testing, this kind of “free from gravity” feeling also affects users significantly.

Things that Hover

Concept

Future computers will be equipped with no mouse, no keyboard, no monitor; this is the concept of ubiquitous computing. For input devices, a lot of smart phone devices employ multi-touch input method instead of mouse or keyboard. On the other hand for output, we still highly depend on display devices to get digital information understandable in real-world.

In order to represent digital information in real-world, display devices are not mandatory. There are some previous approaches called kinetic organic interface [15] which physically change shape of objects. To convey any digital information, capabilities of physical movement of real objects are essential for human computer interaction. Each tiny physical robot on desktop, as a future digital pixel, should be able to move freely by itself. This research is strongly motivated by the concept of above thought.

There exist two problems in this robotic approach; the actuation method and the battery problem. Typical DC motor or stepper motor used in robots are too heavy for lightweight tiny robots. Our proposed system solves this problem by using contact-less powering from desktop surface to hover objects by lightweight piezoelectric actuator which blows air.

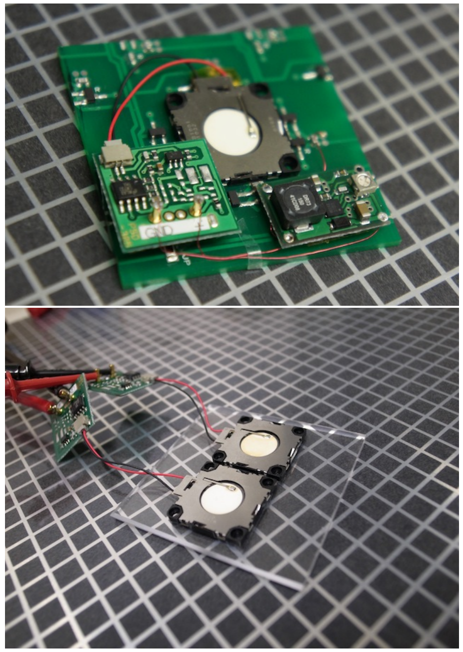

Figure 2: Prototype system. (Two different functionalities in two implementations: powering from 2D sheet (top) and moving direction control (bottom).)

System overview

Figure 2 shows the appearance of our Things that Hover node. A Things that Hover node consists of acrylic board combined with printed circuit board (PCB) that has rectifier, and microblower piezoelectric actuators from Murata on top of the body. To make the body hovering, our installation has been designed as light as possible.
Desktop surface should be covered with 2D power sheet which is described in later section. This sheet has simple three-layer structure. Due to this simplicity, in the future, flexible fabric just like table cross can be made as the power sheet.

Hovering by Microblower

Piezoelectric actuator

The Microblower from Murata Manufacturing Co., Ltd.[1] has piezoelectric ceramic based drive mechanism that allows a compact and thin unit. With the dimensions of 20 x 20 x 1.85 mm, it is capable of significant air discharges: 1,900 Pa (maximum static pressure at 15V p-p) and 1 liter per minute (at 15 V p-p and under 100 Pa back pressure). Due to its piezoelectric drive system, the device also offers lower power consumption than more common air-cooling devices like an ordinal DC cooling fan.

Hovering model

Flexible skirt system:
A typical hovercraft has a flexible skirt system on the bottom periphery of the body which is developed in 1960's by Christopher Cockerell. Figure 3(c) shows mechanism of this flexible skirt system. The blown air inflates the skirt under the vehicle. Airflow blowing down to ground surface lifting up the whole body of the hovercraft by forcing high pressure air under the craft.

Plenum chamber system:
However this flexible skirt structure is too complex for tiny desktop objects. In this research, we applied a plenum chamber system that is simpler to implement. Figure 3(b) is a cross section of this system. A plenum chamber is a housing for air at positive pressure. Charged air in positive pressure will lift up the body and flow under the edge. This

[1]http://www.murata.com/products/micromechatronics/feature/microblower/index.html

is much simpler than flexible structure for tiny implementation. We employed this plenum chamber structure and combined with the microblower in order to create a tiny hovering craft as shown in Figure 4. The airflow blown down by the actuator fills the chamber, and lifts up the body.

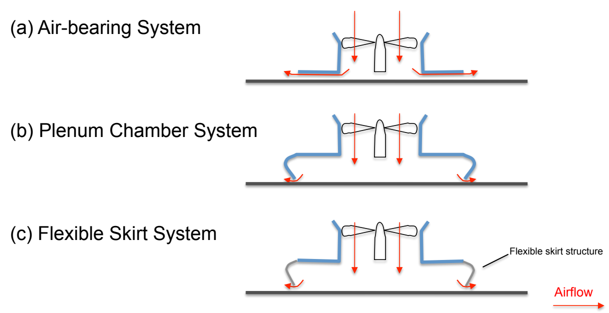

Figure 3: Hovercraft structure (a) Air-bearing System: most simple but low lift up power. (b) Plenum Chamber System: simple structure. positive pressured air in the chamber lifts up body. (c) Flexible Skirt System: commonly used in recent hovercraft.

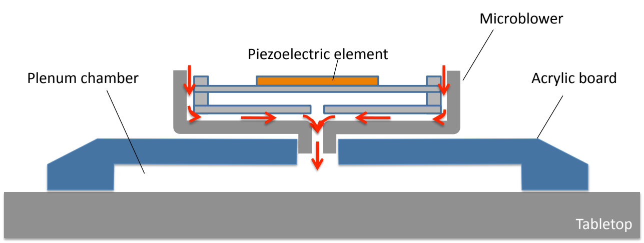

Figure 4: Cross section view of Things that Hover system

[2]http://www.ettus.com/products

Powering from desktop surface

2D power transmission (2DPT)

One of the 2DPT methods introduced in Shinoda Lab. [13] is based on microwave signals. In this method, a 2D sheet composed of two conductor layers at the top and bottom and a dielectric layer at the middle, conduct the high frequency (in microwave range) signals. Due to its limited impedance, as seen in Figure 5, passing signal inside the sheet leaks out of the top conductive layer. The leaked signal, which is achievable if the antenna could be in close proximity of the sheet, can be used for power providing or data communication.

Figure 6 shows a simple setup for power and data transmission via 2D sheet. At the transmitter side, a laptop together with a USRP software radio node[2] generates an RF signal at 2.4 GHz. After amplification, the signal that can be a carrier or modulated signal is used to feed the sheet. At the receiver side, a coupler with a set of USRP node and laptop is used to monitor the received signal. In the case where only contact-less power providing is considered (like LED lightening), only a rectifier to extract the DC power is needed.

Due to the limited dimensions of the sheet and the reflection of the signal from the edges resulted in an standing wave at the sheet, the achievable power has a periodic behavior, i.e. by moving of the coupler on the sheet, the received power level fluctuates. As expected, the distance between the two neighboring points with maximum power is about 5 cm, which is approximately equal to half the wavelength of the signal fed into the sheet. Figure 7 represents the power fluctuations.

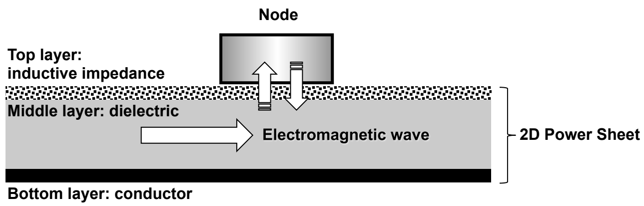

Figure 5: 2D Power Sheet in cross section.

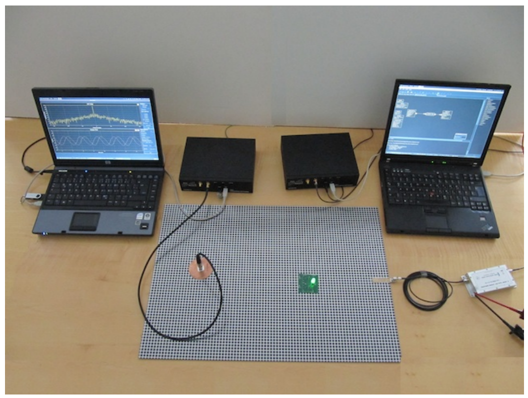

Figure 6: An example of 2DPT application.

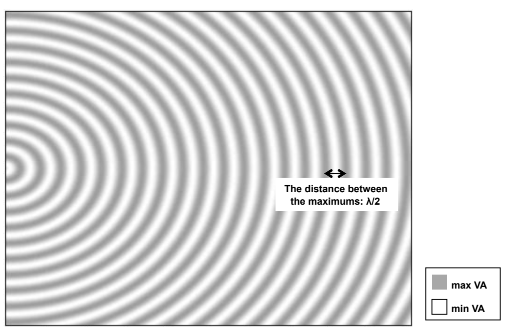

Figure 7: Power fluctuations on 2D sheet

Prototype System

Implementation

This section illustrates our implementation of Things that Hover system from the perspectives of powering from 2D sheet part and moving direction control part.

Integration of 2D sheet powering and actuation

We attached thin acrylic bridge under the rectifier PCB to create a plenum chamber for hovering. Under this condition, derived voltage from rectifier output varied from 2.12 to 3.62 V in maximum. This output is up converted to 18 V and amplified by OpAmp to generate 15 Vp-p waveform to drive piezoelectric actuator as shown in Figure 8. From initial result, derived energy from 2D sheet successfully boosted a actuator in enough power, and lifted up the body.

In order to get stable power from 2D power sheet even when the object is moving over, some additional mechanisms like signal normalization or temporal energy charging is needed. These are described later in discussion section.

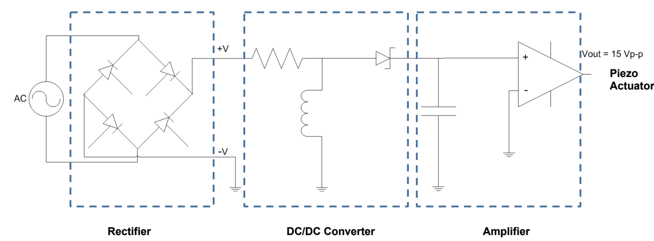

Figure 8: Piezoelectric actuator driving circuit: Rectifier, DC/DC converter, OpAmp is integrated on the node.

Direction control

To get directional control for hovering object, we employed multiple chamber system shown in Figure 9. Each chamber is filled with a different microblower. When the object moves, supplied voltage to piezoelectric driver is balanced by pulse width modulation. Due to this differential control of multiple microblowers air and slit under the object, propulsion force in horizontal direction is generated.

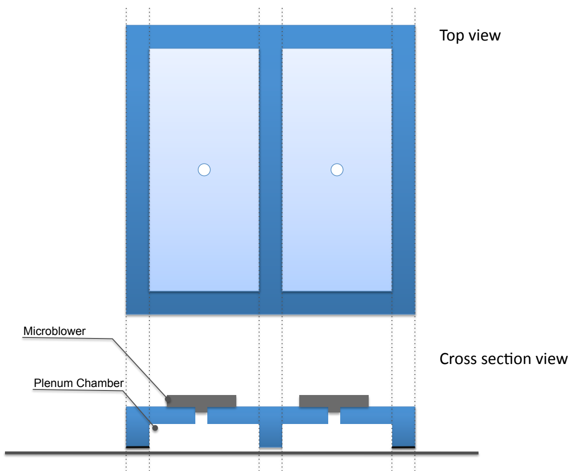

Figure 9: Two-chambers system for bi-directional movement

Discussion

We designed and proposed the prototype of Things that Hover in this paper, to explore two-way physical interaction with daily objects as highly distributed tangible user interfaces. Although still in a early stage, these explorations have depicted a number of interesting research questions. We are now focusing on the following directions as our future work: position sensing, integration, omnidirectional movement and inter-object communication. Following section describes each of them.

Position sensing

We presented implementation of how to move object using piezoelectric actuator in previous section. Along with actuation, position sensing mechanism is essential to create interaction devices. Although hovering object with piezoelectric actuator reduces friction from surface, that also means it needs accurate position sensing method for stable control of objects.

One of a possible solution for this problems is a camera based fiducial tracking method such as used in surface computing research [8]. 2D barcode marker and image feature extraction from outside camera enables easy position sensing in accurate quality. However this research aims for developing fundamental technology which can be used even in home environment. Therefore a position tracking mechanism which does not depends on environmental facilities is suitable.

Now we are investigating optical mouse sensor based relative position sensing methods. Optical mouse sensor has low resolution but high frequency image sensor in it to detect moving direction. If each moving node has this cheap sensor and a micro controller on it, relative position sensing is possible in a feasible way. Moreover, there are possibilities to detect whether the object was touched or not by observing inertial movement.

Integration

As described in implementation section, we now have separated implementations one gets power form 2D sheet, and the other one controls direction of movement. These parts should be integrated to be one as our design goal. Main difficulty lies on stability of derived power from 2D sheet. Because of characteristics in frequency modulation, there exists energy bias that depends on position of rectifier on the sheet.

To achieve the power stability, two types of approaches are possible. One is adding super capacitor to node for charging energy. From preliminary testing with a super capacitor (4F, 2.5V), we got 150 to 200 seconds to charge and it can drive an actuator for 20 seconds. It is still short for longer movement, but this kind of charging model can be applicable for specific situations. The other one is stabilizing energy bias on the sheet by multiple input channels. Theoretically, multiple channel inputs after splitting source signal cause more stabilized fluctuations on the sheet. Using this setup with more smaller capacitor could resolve this difficulty, but there needs further investigation about fundamental characteristics of the sheet.

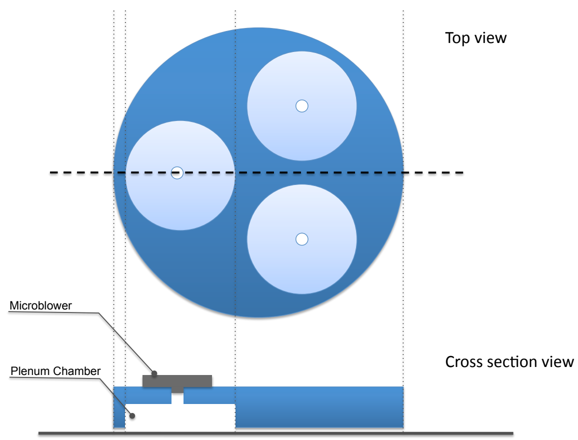

Figure 10: Three-chambers system for omnidirectional movement.

Omnidirectional movement

Our implementation showed bi-directional movement of real object by using two actuators. For omnidirectional movement on desktop surface, at least three actuators are needed for control as shown in Figure 10.

Inter-object communication

As we described in the power sheet description, it is also possible to communicate with other nodes through the sheet itself. Ideally, power transmission and data communication should be done in simultaneously. However to do that, integration of rectifier which derives power and antenna (so called rectenna) is essential.

Another possibility is using a wireless communication channel only for data communication. Comparing to actuating microblowers, additional few milliwatt will be consumed by network communication. Anyway, with integration of our method with sensor networks on multiple robots, a lot of research possibilities will be revealed between CHI and network communities.

Potential applications

By using proposed method, following applications are potentially available.

Real-time simulation:
Because of its capability of self movement, our system is also suitable to present real-time physical simulation. Not only presenting contents, users also can continuously interact with the objects, and those physical objects can be react based on calculation result by computers. This kind of real-time cooperation through physical activity will cause deeper understanding of simulated contents.

These capabilities can also be applicable to education, entertainment or game system. Like LEGO Mindstorm or programmable brick for kids [11], an educational system which children can learn through physical language can be created using this architecture. This kind of two-way interaction with haptic and kinetic experience will also enhance the entertainment as described in [4]. Note that the system doesn't have mechanical motors or joints and suitable for totally flat surface, applications that need strong movement or on bumpy surface are not good for use.

Tabletop interaction, user interface enhancement:
Not only as stationary phicon, our technology possibly enables desktop objects act as physical display by its movement. One of the possible examples is status notification by movement. Other than that, combined with kinetic buttons or sliders along with micro controllers, a lot of variation of Things that Hover nodes can be implemented as parts of whole desktop user interfaces.

One limitation on combining with these input devices is its payload. Though its also depends on shape and size of the body, the object cannot carry heavy payload even if multiple actuators are used. Thus extra cares about this limitation are needed for future implementation.

Self-moving particle display:
Though our experimental implementation does not have out put device like LED or small display, it is feasible to add those considering its power consumption. Full-color LED to represent pixel information with plenty of nodes can create large display as a whole [19] with self-organized movement.

Recent technologies of small size display and low power wireless communication make tangible interface research [12] realized even into commercial products[3]. These display and communication technologies can also be integrated with proposed moving objects to support further interactions, but we have been more focusing on actuation part in this paper.

In-store presentation:
Surfaces are not limited to ordinal desktop, any flat surfaces which can have 2D power sheet are enough for moving environment. For example, in-store presentation on rack, in show case, or other situations are also suitable for the application. Friction less movement created by Things that Hover system can attract people and make up effective presentation.

Conclusion

In this paper, we proposed a system named Things that Hover which enables physical two-way interaction in a realistic way. Our approach combines 2D power sheet and piezoelectric actuator to lift up and control moving direction of the object without batteries. We also suggested various potential applications for it, including game, entertainment or simulation. Our current plans are to extend this system to combine with wireless sensor nodes.

Although our current implementation is still in early stage of development, we are convincing that issues discussed in this paper drive future direction of real world user interface. These fusions of physical and digital media suggest many rich opportunities for continuing research.

Acknowledgement

The power sheet and rectifiers used in this research are provided from Shinoda Lab. at the University of Tokyo. We appreciate their kind cooperation. We also would like to thank all the reviewers who have donated their time and expertise for this paper.

[3] https://www.sifteo.com

References

[1] S. Brave, H. Ishii, and A. Dahley. Tangible interfaces for remote collaboration and communication. In *Proc. of CSCW '98*, pages 169–178, Nov. 1998.

[2] R. Brooks. A robust layered control system for a mobile robot. *IEEE Journal of Robotics and Automation*, 2(1):14–23, 1986.

[3] G. W. Fitzmaurice, H. Ishii, and W. A. S. Buxton. Bricks: Laying the Foundations for Graspable User Interfaces. In *Proc. of CHI '95*, pages 442–449, May 1995.

[4] B. Fogg, L. D. Cutler, P. Arnold, and C. Eisbach. HandJive: a device for interpersonal haptic entertainment. In *Proc. of CHI '98*, pages 57–64, Jan. 1998.

[5] P. Frei, V. Su, B. Mikhak, and H. Ishii. curlybot: designing a new class of computational toys. In *Proc. of CHI '00*, pages 129–136, 2000.

[6] H. Ishii. Tangible bits: beyond pixels. In *Proc. TEI '08*, pages xv–xxv, Feb. 2008.

[7] T. Iwai. Composition on the table. In *ACM SIGGRAPH 99 Electronic art and animation*, page 10, 1999.

[8] M. Kaltenbrunner and R. Bencina. reacTIVision: a computer-vision framework for table-based tangible interaction. In *Proceedings of the 1st international conference on Tangible and embedded interaction - TEI '07*, pages 69–74, 2007.

[9] H. Kim and W. Lee. Kinetic tiles: modular construction units for interactive kinetic surfaces. In *Adjunct procc of UIST '10*, pages 431–432, 2010.

[10] S. Kim, H. Kim, B. Lee, T.-J. Nam, and W. Lee. Inflatable mouse: volume-adjustable mouse with air-pressure-sensitive input and haptic feedback. In *Proc. of CHI '08*, pages 211–224, Apr. 2008.

[11] F. Martin, K. Par, K. Abu-zahra, V. Dulsky, and A. Chanler. iCricket: A programmable brick for kids' pervasive computing applications, 2005.

[12] D. Merrill, J. Kalanithi, and P. Maes. Siftables: towards sensor network user interfaces. In *Proc. of TEI '07*, pages 75–78, Feb. 2007.

[13] A. Noda and H. Shinoda. Power transmission coupler for low leakage 2D-communication sheet. In *Proc. of INSS 2009*, pages 1–7. IEEE, June 2009.

[14] G. Pangaro, D. Maynes-Aminzade, and H. Ishii. The actuated workbench. *ACM Transactions on Graphics*, 22(3):699, July 2003.

[15] A. Parkes, I. Poupyrev, and H. Ishii. Designing kinetic interactions for organic user interfaces. *Communications of the ACM*, 51(6):58–65, June 2008.

[16] I. Poupyrev, T. Nashida, S. Maruyama, J. Rekimoto, and Y. Yamaji. Lumen: interactive visual and shape display for calm computing. In *ACM SIGGRAPH 2004 Emerging technologies*, page 17, Aug. 2004.

[17] J. Rekimoto, B. Ullmer, and H. Oba. DataTiles: a modular platform for mixed physical and graphical interactions. In *Proc. of CHI '01*, pages 269–276, 2001.

[18] D. Reznik and J. Canny. C'mon part, do the local motion! In *Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation (Cat. No.01CH37164)*, pages 2235–2242. IEEE, 2001.

[19] M. Sato, Y. Suzuki, S. Nishizaka, Y. Torigoe, A. Izumihara, A. Hiyama, K. Nishimura, T. Tanikawa, and M. Hirose. Highly integratable large-scale displays for public spaces. In *Adjunct Proc. of Ubicomp '10*, pages 427–428, 2010.

[20] B. Ullmer and H. Ishii. mediaBlocks: tangible interfaces for online media. In *Proc. of CHI '99 EA*, pages 31–32, May 1999.

[21] M. Weiss, F. Schwarz, S. Jakubowski, and J. Borchers. Madgets: actuating widgets on interactive tabletops. In *Proc. of UIST '10*, pages 293–302, 2010.