Siftables: Towards Sensor Network User Interfaces

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ABSTRACT
This paper outlines Siftables, a novel platform that applies technology and methodology from wireless sensor networks to tangible user interfaces in order to yield new possibilities for human-computer interaction. Siftables are compact devices with sensing, graphical display, and wireless communication. They can be physically manipulated as a group to interact with digital information and media. We discuss the unique affordances that a sensor network user interface (SNUI) such as Siftables provides, as well as the resulting directness between the physical interface and the data being manipulated. We conclude with a description of some gestural language primitives that we are currently prototyping with Siftables.

Author Keywords
Sensor Network User Interface (SNUI), Tangible User Interface (TUI), Sensor Network, Siftable Computing Interface

ACM Classification Keywords
H.1.2: Models and Principles: User/Machine Systems. H.5.2: Information Interfaces and Presentation: User Interfaces. K.8.0: Personal Computing: General. J.7: Computer Applications: Computers in Other Systems.

INTRODUCTION
The development of new technologies often spurs new ideas in human-centric design philosophies. Currently there is a great deal of activity in wireless sensor networks in which many computationally-equipped nodes cooperate to perform a wide variety of tasks. However, sensor networks[1] have not yet induced a coherent set of design principles for HCI problems. Specifically, little research effort has been invested in using sensor networks as user interfaces. In this paper, we propose applying principles from sensor network technologies to TUI research in order to open up new interaction possibilities. We call this class of distributed TUIs Sensor Network User Interfaces (SNUIs)[2].

We first compare some existing HCI paradigms to the possibilities afforded by a distributed tangible user interface (dTUI). We then discuss Siftables, an example of the dTUI. Next we sketch out some elements of an interaction language for Siftables. We conclude with challenges and future work in this area.

BACKGROUND AND MOTIVATION
The design of Siftables was inspired by observing the skill that humans have at sifting, sorting, and otherwise manipulating large numbers of small physical objects. When we overturn a container of nuts and bolts and sift through the resulting pile to find one of a particular size, or spread photographs out on a tabletop and sort them into piles, we use all of our fingers and both hands actively and efficiently. However, when we sort digital information or media such as digital photographs or emails, the experience typically does not leverage our physical manipulation skills. One typical user interaction with a modern graphical user interface (GUI) is to click on an icon with the mouse, drag it to another location on the screen, and drop it to reposition it or to assign the data it represents to a folder. This so-called 'direct manipulation' of information afforded by a GUI is a poor substitute for our facile all-finger, two-handed manipulation of physical items.

Two Types of TUIs
Tangible user interfaces (TUIs) have made great progress towards leveraging our physical manipulation abilities to interact with digital information. Fitzmaurice et al. [2] pioneered physical 'handles' to digital objects. TUIs with handles operate by sensing the user's manipulation of each handle, and displaying a co-located visual representation of the data being manipulated. Some TUIs like the Designer's Outpost [3] and DataTiles [4] project graphics onto the handles themselves, while others like SenseTable utilize them simply as generic tangible cursors to the overlaid GUI. TUI advantages over GUIs include support for two-handed input (though

[1] In this paper we will use the common term 'sensor network' to imply a wireless sensor network in which each node is physically independent, self-powered and can communicate with its peers via a wireless radio.

[2] In 'Experiences and Directions in Pushpin Computing' [1], Lifton et al. use the acronym SNUI to describe an interface allowing a user to interact with a sensor network. Our usage implies that the sensor network *is* the user interface itself.

Figure 1. A physical sorting task, with nuts and bolts (left), manipulating a physical mockup of Siftables (center), and interactions with the first working prototype (right)

recent touch-screen interfaces also support this [5]), reduced cognitive load as compared to a GUI, faster target acquisition, and a reduction in the level of indirection between a person's hand and the actual computation taking place when adjusting a parameter [6]. These features make handle-based TUIs a more direct form of manipulation than the GUI alone.

Another class of tangible user interface largely dispenses with the GUI paradigm, featuring physical objects that directly embody the digital information or media that they represent. Ishii's Music Bottles [7] and Want et al's work with embedded RFID tags [8] are examples of TUIs that do not implement handles to manipulate a GUI overlay. Instead, the shape and features of the objects themselves suggest the semantics of the interaction. The inherent coupling between form and function in this second class of TUIs brings an increased directness to an interaction with digital information or media. However, this gain in directness comes at a cost: Since they represent the underlying data implicitly with their physical form, UIs featuring special-purpose objects can be more limited to a particular application domain or style of interaction.

Sensor Network User Interfaces

The tradeoff between the direct interaction of implicit affordances verus the polymorphic behavior possible in a 'handles+GUI' system led the authors to consider how the design space might be expanded. With Siftables we explore how sensor network technologies might be combined with features from the GUI and TUI in order to further increase the directness of a user's interaction with digital information or media. Sensor networks consist of collections of sensing and communication devices that can be distributed spatially. They are capable of exhibiting coordinated behavior, forming a kind of 'functional fabric' in the spaces that they inhabit without requiring external sensing or power infrastructure. Sensor network nodes can be built with an array of sensing technologies that can be used to build rich models of local interactions and their surroundings.

Our conception of a Sensor Network User Interface (SNUI) takes the form of a distributed TUI in which many small physical manipulatives have sensing, wireless communication, and user-directed output capabilities. These devices can host

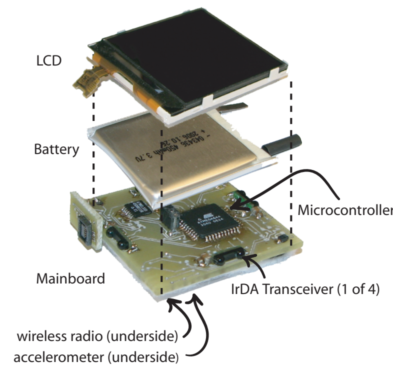

Figure 2. The components of a Siftable computing element

a representation of a wide range of digital data, and they can be physically manipulated as a group as a tangible interface to the data. They are a generic interaction platform that combines the flexible graphical display capabilities of the GUI with the physicality of a TUI, coupled with the capabilities of a sensor network. In contrast to TUIs that provide handles to a projected digital representation of data, a SNUI operator holds a representation of the data itself that can be perceived and altered directly. Though it increases system complexity for SNUI designers, we expect the greater functional capabilities at the level of the individual interaction node to make the task of maintaining 'sync' between the digital and physical representations of data more straightforward, and without requiring external infrastructure such as a projector or an augmented tabletop surface. Also, a SNUI can be more easily reconfigured than the corresponding manipulatives of a single-purpose TUI [9] built to utilize a particular sensing modality and form factor.

This particular combination of technologies are only now becoming inexpensive and widely available, and we believe that SNUIs will enable a new degree of directness in physically manipulating and interpreting information and media.

SIFTABLES

Siftables consists in a collection of compact tiles (36mm x 36mm x 10mm) - each with a color LCD screen, a 3-axis accelerometer, four IrDA infrared transceivers, an onboard rechargeable battery and an RF radio. For a typical data manipulation task, each tile is populated via radio with a representation of a single instance of the data to be sorted, and a user's physical manipulations to the collection of tiles are sensed and used as input to the system. Visual feedback during the task is presented to the user on the LCD display, and auditory feedback can be played by a nearby computer.

Sensing in the current Siftable design is accomplished by the accelerometer and the IrDA transceivers. Manipulated atop a flat surface, a siftable can sense its own motion in the plane of the surface, as well as impacts with other objects. It can also sense the action of being lifted, tilted or shaken. The four IrDA transceivers are tuned for extremely short-range communication on the order of 1cm, and are used to detect neighboring tiles at close range. The sensed information can be shared with other siftables or with a nearby computer wirelessly. These sensing, graphical display and wireless communication capabilities allow siftables to behave as a single, coordinated interface to information and media.

TOWARDS A SIFTABLE INTERACTION LANGUAGE

Perhaps the most interesting aspect of Siftables is that it is a platform upon which we can develop an interaction language for SNUIs. We have begun to invent a library of manipulations and metaphors analogous to point-and-click or drag-and-drop for the GUI, but related specifically to the SNUI.

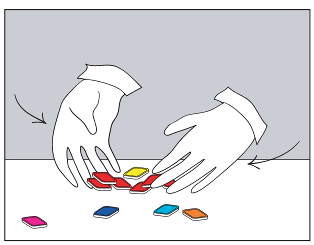

Figure 3. Grouping: Pushing siftables together into a pile could group or apply a common tag to the corresponding data.

We find certain existing work related to our conception of a SNUI interaction language. The 'Smart-Its Friends' technique of pairing two personal devices by shaking them together at the same time is an example of grouping-by-gesture [10]. Hinckley [11] discusses several interactions based around the bumping of display screens into each other, including cooperative display sharing to create a larger viewing area for documents or photographs. Both projects make use of inertial data captured from an accelerometer, and are novel physical interactions with devices that could be adapted for use by a SNUI. BumpTop is a GUI-based interface that simulates the physics of real-world objects with inertia [12], and prototypes a wide range of gestural language primitives for interactions with icons.

Our interaction language for Siftables is still in the early stage of design. The interactions that we outline in this section are physical manipulations to single or multiple siftables that can be sensed with the current onboard sensors. See the figure captions for suggestions regarding the semantic meaning that each manipulation could have to an interaction with information or media. These interaction primitives are just a few of a wide range that can be created for Siftables across varying application areas.

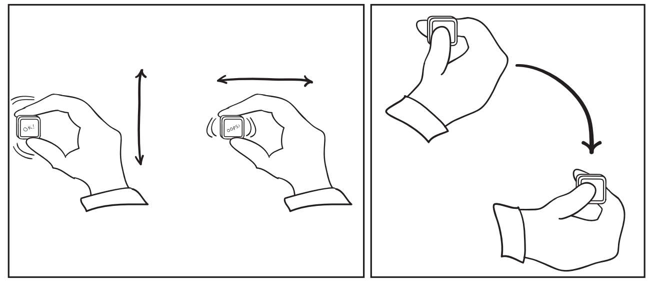

Figure 4. 'Yes/No' Gestures (left): A user could shake a siftable vertically or horizontally to give positive or negative feedback to the system. 'Sugar Pack Snap' Gesture (right): A user could snap a siftable sharply in the downward direction to clear its current data association

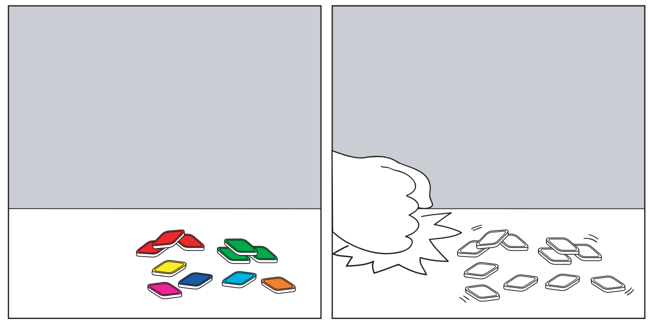

Figure 5. Thump Gesture: A user could thump their fist on the table, bumping all siftables at once to swap in a new set of data associations.

Example Application: Photo Sorting

A task particularly well-suited to Siftables is digital photograph organization. With Siftables, the task of sorting digital images could be much closer to a physical photograph organization activity that leverages a users' manual dexterity. Thumbnails of the photographs to be sorted are transmitted to the siftables by a host computer wirelessly. A user can then create groupings by pushing siftables into piles. The

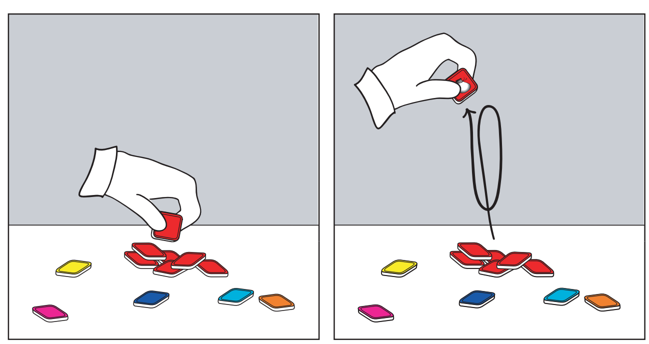

Figure 6. Gather: With this gesture a single siftable from an established group can be made to represent all data from the group.

devices will sense these movements and impacts using their accelerometers, and will use their radios to share information about these events amongst each other. When more than one siftable is bumped at nearly the same time, a grouping will be created back on the host computer. We are now prototyping this photo sorting application, and with user feedback we expect to add further useful manipulation affordances.

CHALLENGES AND FUTURE DIRECTIONS

The development of Siftables is still at a very early stage. As such there are many future challenges to address, both technological and conceptual.

The sensor network community has focused a great deal of effort on the technical issues that it faces. Many of these present themselves as tradeoffs in the design space. Longer battery life for a sensor node requires that other priorities such as battery size, radio transmit range, or frequency of communication must suffer. The use of ultra-small components can cause the device to require more specialized and expensive assembly, so they may be avoided in favor of larger components, resulting in a larger device. Other challenges relate to implementing the desired sensor network behavior, such as coordinated sensing of events and mobile code that be transmitted easily to another node and run immediately [13]. Siftables and other SNUIs will thus take advantage of the continuous progress in the sensor network field.

Although tradeoffs that the sensor network community targets tend to be more practical than conceptual, navigating them is an essential activity in building a SNUI today. Our primary technical challenge is in powering the siftables. Driven by small lithium-polymer batteries, they must be recharged relatively frequently. We are currently investigating alternatives such as inductive charging to improve this characteristic. We also intend to implement a richer set of input and output capabilities that we can use to prototype new application scenarios, such as additional sensing modalities (i.e. capacitive), and output capabilities such as auditory or tactile. Finally, we plan to more fully develop the Siftable physical interaction language from our first steps described here.

CONCLUSION

Tangible user interface research has provided a rich set of design principles for addressing human-computer interaction problems. We have proposed taking these design principles and applying sensor network technologies to them in an attempt to both yield new kinds of tangible interfaces and new design principles specific to the possibilities inherent in Sensor Network User Interfaces (SNUIs). Our Siftable Computing Interface represents an initial step into this space; we hope that it will be the first of many.

ACKNOWLEDGMENTS

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REFERENCES

1. Lifton, J., Broxton, M., Paradiso, J.: Experiences and directions in pushpin computing. Proceedings of the 4th international symposium on Information processing in sensor networks (2005)
2. Fitzmaurice, G.W., Ishii, H., Buxton, W.: Bricks: Laying the foundations for graspable user interfaces. Proceedings of CHI'05 (1995) 422–449
3. Klemmer, S., Newman, M., Farrell, R., Bilezikjian, M., Landay, J.: The designers' outpost: a tangible interface for collaborative web site. Proceedings of UIST'01 (2001) 1–10
4. Rekimoto, J., Ullmer, B., Oba, H.: Datatiles: a modular platform for mixed physical and graphical interactions. In: Proceedings of CHI '01, New York, NY, USA, ACM Press (2001) 269–276
5. Han, J.Y.: Low-cost multi-touch sensing through frustrated total internal reflection. In: Proceedings of UIST'05, New York, NY, USA, ACM Press (2005) 115–118
6. Fitzmaurice, G.: Graspable User Interfaces. PhD thesis, University of Toronto (1997)
7. Ishii, H., Mazalek, A., Lee, J.: Bottles as a minimal interface to access digital information. In: CHI'01 Extended abstracts on human factors in computing systems, New York, NY, USA, ACM Press (2001) 187–188
8. Want, R., Fishkin, K.P., Gujar, A., Harrison, B.L.: Bridging physical and virtual worlds with electronic tags. In: Proceedings of CHI '99, New York, NY, USA, ACM Press (1999) 370–377
9. Frei, P., Su, V., Mikhak, B., Ishii, H.: curlybot: designing a new class of computational toys. In: Proceedings of CHI'00, New York, NY, USA, ACM Press (2000) 129–136
10. Holmquist, L., Mattern, F., Schiele, B., Alahuhta, P., Beigl, M., Gellersen, H.: Smart-its friends: A technique for users to easily establish connections between smart artefacts. Proceedings of UbiComp'01 (2001) 116–122
11. Hinckley, K.: Synchronous gestures for multiple persons and computers. In: Proceedings of UIST'03, New York, NY, USA, ACM Press (2003) 149–158
12. Agarawala, A., Balakrishnan, R.: Keepin' it real: pushing the desktop metaphor with physics, piles and the pen. In: Proceedings of CHI'06, New York, NY, USA, ACM Press (2006) 1283–1292
13. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E.: Wireless sensor networks: a survey. Computer Networks **38**(4) (2002) 393–422