SparKubes: Exploring the Interplay between Digital and Physical Spaces with Minimalistic Interfaces

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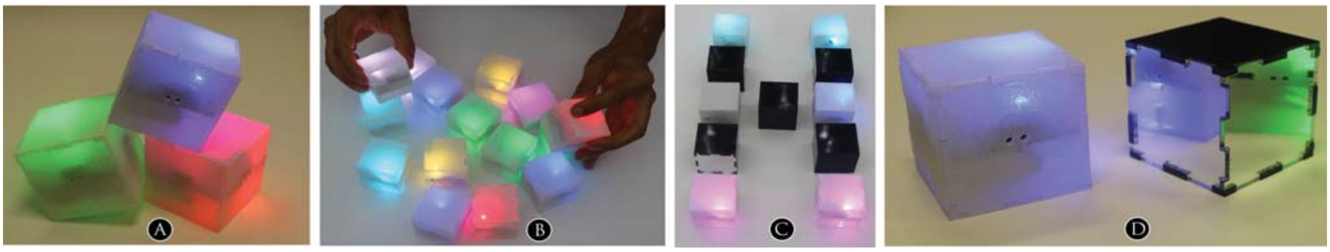

Figure 1: (a) SparKube, (b) Direct manipulation, (c) Indirect manipulation and (d) Indirect manipulation with mirror cubes.

ABSTRACT

Tangible objects have seen an ongoing integration into real-world settings, e.g. in the classroom. These objects allow for instance learners to explore digital content in the physical space and leverage the physicality of the interface for spatial interaction. In this paper, we present SparKubes, a set of stand-alone tangible objects that are corded with simple behaviors and do not require additional instrumentation or setup. This overcomes a variety of issues such as setting up network connection and instrumentation of the environment–as long as a SparKube sees another, it "works". The contribution of this paper is three-fold: we (1) present the implementation of a minimalistic tangible platform as the basis for SparKube, (2) depict the design space that covers a variety of interaction primitives and (3) show how these primitives can be combined to create and manipulate SparKube interfaces in the scope of two salient application scenarios: tangible widgets and the manipulation of information flow.

ACM Classification Keywords

H.5.2 Information Interfaces and Presentation: User Interfaces

INTRODUCTION

The traditional goal of tangible interaction is to bring the interactivity into day-to-day environments by embedding objects with significant computational capabilities, multiple sensors and actuators [5]. Inspired by minimal interfaces such as "musicBottles" [4], we designed SparKubes, a set of tangible objects to explore the interaction space between digital and physical spaces. These stand-alone tangible objects are corded with simple behaviours and do not require additional instrumentation or setup. Hence, there is no need to instrument the environment or setup any network connections as in prior work [7]. As long as SparKubes see each another, it "works". These characteristics particularly pertain to noisy settings such as a classroom filled with young learners. We believe that SparKubes can specifically make a contribution to foster play-based learning through tangible interaction, as well as early exploration of computing paradigms such as windows, icon, mouse and pointer (WIMP).

With SparKubes, we present a minimalistic input/output device, which can interact with non-computational objects to create, simple interactive systems. SparKubes use the flow of light as the principle of operation. Conceptually, SparKubes are designed to accept light from one direction, process the encoded information in it, and then pass the light on to another direction. Communication between SparKubes can be manipulated by (a) direct interaction with and on the cube, (b) (re-) arranging the layout or adding/removing cubes and (c) using physical objects (e.g. a mirror to guide the light towards a specific direction or cube).

The contributions of this paper is three-fold:

- Design and implementation of a minimalistic tangible I/O platform
- Exploration of the interaction design space, comprising a set of SparKube interaction primitives
- An exemplary set of applications that showcases how to create and manipulate SparKube-based tangible interfaces with application in educational settings and beyond.

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RELATED WORK

Physical interactions with digital objects have been explored utilizing different aspects of the physicality such as the intuitiveness[5], playfulness[9] and interactivity[6].

One of the main advantages of physical interaction is its spatiality. Most of the commercially available computer interfaces have limited spatiality and are primarily limited to two dimensional interactions. Physical interactive devices naturally extend the spatiality of interfaces. A prominent example is Siftables [7], compact devices with wireless sensing capabilities and a graphical display that can be used to interact with digital content. Pla and Maes presented Display Blocks, a small cubic block with a display embedded in each side, as a solution to dimensional compression and physical-digital disconnection [8]. In the same vein, Coelho et al. [2] developed Six-fourty by Four-eighty, a low resolution display that leverages on interactive single-pixel devices where pixels can be arbitrarily arranged.

It has been shown that physical interactive components leads to more engagement than their traditional counterparts. This can be attributed to either their playfulness or accessibility. Topobo [9] is one of the many great examples of how physical playfulness, can be enhanced using computational objects. Tangible interfaces for locative media interactions in a ubiquitous computing environment were explored in [11]. It allowed abstract digital information to be situated in physical space and quantified through visual feedback from a tri-color LED. The representation of the digital information flow using multiple tangible objects allows for the visualization of e.g. complex data flows. SparKubes combine physicality and spatiality in to a single pixel UI.

SPARKUBES

A SparKube is a cube-shaped tangible object that can sense its orientation, tap and can communicate with other SparKubes through infrared light that is both emitted and received on each side of the cube. These light transceivers on each side of the cube are “always-on”. SparKubes are unique as they are standalone, require no setup and also do not rely on any instrumentation of the environment. SparKubes go beyond prior work as they expose three salient affordances:

1. **Natural Properties:** The communication and therefore the interaction with SparKubes mainly pertain to interacting with light that is emitted and received by the cubes. Manipulating the beam of light thus directly impacts the SparKube interaction. For instance blocking the light with a hand or finger interrupts the light (similar to infrared multitouch frames).

2. **Minimal Constraints:** Since SparKubes are stand-alone tangible objects and require neither additional instrumentation nor any setup, there is only little constraint in designing a minimal tangible user interface with SparKubes. In particular, SparKubes do not require a user to place them very near to each other (as with e.g. NFC) or establish a physical connection between them. Distance between cubes can thus be arbitrary and is only limited by line of sight.

3. **Responding to Analog Objects:** SparKubes integrate with arbitrary physical objects to design unique minimal user interfaces. In particular, analogue objects such as blocks or mirrors can be used to block or respectively guide the light emitted by the cubes. Also, other objects such as prisms can leverage on SparKube’s optical properties to explore novel interfaces.

Hardware Implementation

In order to explore the interaction space between computational and non-computational spaces, we designed and built a series of functional SparKube prototypes. They comprise of a collection of 20 cubes (40mm x 40mm x 40mm), each containing a small form factor custom PCB (36mm x 36mm) with all the hardware needed onboard. The hardware architecture of SparKubes consists of an RGB LED, a 3-axis accelerometer, four IrDA infrared transceivers, a PIC24F Microchip microcontroller and a compact onboard rechargeable lithium ion battery.

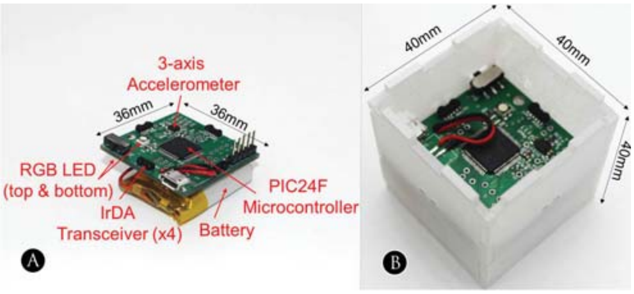

Figure 2: Implementation of SparKubes (a) Custom PCB (b) Casing with PCB inside

Each SparKube runs on the same code platform. Communication between cubes is fostered through infrared light, hence no network connection is required, only line of sight between cubes. In addition to providing the communication basis between SparKubes, the four IrDA transceivers can also be used to communicate with any device that supports IrDA (e.g. computers, smartphones). IrDA transceivers are tuned for a range of about 20 cm. We found that this is the ideal range, allowing SparKubes to interact with non-digital objects (e.g. mirrors) without interferences between cubes when the user interacts with many of them. In the current SparKube implementation, general sensing is accomplished by the accelerometer and the IrDA transceivers. As a minimal I/O device, visual feedback is provided by an RGB LED, resembling a single-pixel device.

INTERACTION DESIGN SPACE

In the following, we illustrate the interaction primitives of a SparKube interface and then show how these can be combined to derive interaction concepts for SparKube applications. The set of interaction primitives can be subdivided into three major categories: information flow control, direct manipulation and indirect manipulation. The interaction primitives and application scenarios are also demonstrated in the video figure accompanying this paper (cf. `https://www.youtube.com/watch?v=oFT413iMIew`).

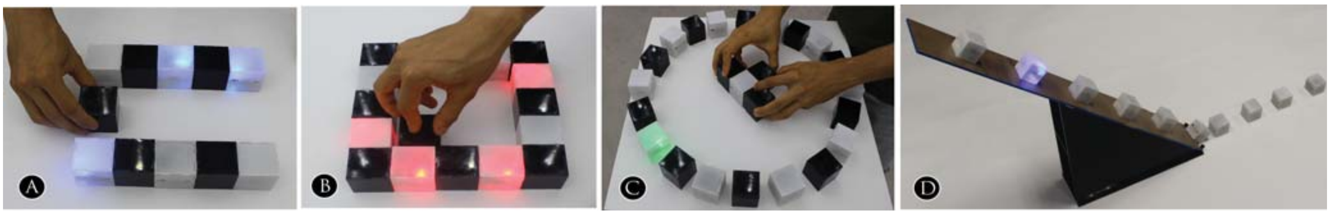

Figure 3: Implementation of SparKubes Widgits (a) 1D Touch (b) 2D Multi-touch (c) Radial Selection Widget (d) Non-planar Input

Information Flow Control: The always-on transceivers in each cube are used to sense other cubes in the vicinity. That way, the information flow between cubes can be controlled: *introducing* a cube into the line of sight of another enables the information flow between them. *Withdrawing* a cube stops the information flow, respectively. *Daisy-chaining* further cubes propagates and redirects the information flow along the chain. The information flow can be *decoupled* by connecting more than two sides of a cube to other cubes.

Direct Manipulation: Users can interact directly with a cube. A SparKube can sense a *tap* on each side. Also, the cubes support *tilt-based interactions*. In the same vein, a SparKube can sense a *shake*.

Indirect Manipulation: In addition to interacting directly with a cube, physical objects can be used to manipulate the emitted light beam of each cube. For instance, everyday objects that do not channel or diffuse light can be used to *block* the light flow. Moreover, a mirror can be used to *reflect or redirect* light.

SPARKUBE APPLICATIONS

In the following, we illustrate how the interaction primitives outlined above can be combined to create and (re-)program minimal tangible user interfaces with SparKubes. The applications comprise (a) tangible widgets and (b) manipulation of information flow.

Tangible Widgets

SparKubes can be used to create a variety of low resolution tangible widgets that can control different appliances, e.g. an application on a nearby computer, wall-sized display or mobile device. The following subsets of interactions are inspired by pioneering research such as iStuff [1], Phidgets [3] or .NET Gadgeteer [10].

1D Single Touch

One dimensional widgets such as scrollbars and 1D selectors can be implemented with SparKubes without modifying its basic behavior. For instance, SparKubes are arranged alternately with light blocking components (e.g. black cubes) in two different lines such that components of the same type in one line are facing components of the same type in the other line (cf. Figure 3 (a)). Light blocking components are required to avoid communication between adjacent SparKubes. The number of utilized SparKubes defines the resolution of the widget (i.e. the more cubes, the higher the resolution). SparKubes can be added and removed on-the-fly while the system is running. A 1D touch can then be recognized by touching the area between two opposite cubes (cf. Figure 3 (a)), since this interrupts the communication between the two cubes. Moving the hand towards one of the ends then translates to e.g. the movement of a scrollbar.

2D Multitouch Surface

Two dimensional touch surfaces can be implemented using the same principle of operation described above. In this case, one line of SparKubes and light blocking components is added perpendicularly at the beginning and at the end of the previous ones. That way, a rectangular-shaped area frames a two-dimensional touch area (cf. Figure 3 (b)), similar to commercially available IR-based multi-touch frames. Again, a touch is recognized through an interrupted communication between two opposite cubes for each axis. The number of touchpoints is constrained by the number of cubes.

Radial Selection Widgets

As a further variation, radial selection widgets such as pie menus can be created by arranging a set of SparKubes in a circular shape and daisy-chaining them (cf. Figure 3 (c)). An SparKube placed in the centre of the circle can then be used to point to a particular cube in the daisy chain, which then translates to a selection (cf. Figure 3 (c)). Again, the resolution of the menu is bound by the number of SparKubes in the chain. The very same setup can be used to mimic the behaviour of tangible knobs to control e.g. the volume of a media player.

Non-planar Input

The ability for SparKubes to measure tilt opens up other possible interactions with the environment they are deployed in. In non-planar surfaces, SparKubes react differently depending on its tilt angle, hence affecting the speed of information transfer. For example, Figure 3 (d) shows SparKubes in an incline. As a result, when the information flows downward, each cube will light up for shorter period. This allows applications to visualize difficult concepts like acceleration.

Manipulation of Information Flow

The nature of the hardware implementation of SparKubes enables a set of seamless interactions between both computational devices and cubes. For instance, a computer containing an IrDA module can easily communicate with SparKubes: cubes can transfer/retrieve the light flow both to and from the computer. That way, these computational devices become part of the very same communication flow that can be manipulated by the interaction primitives outlined above (cf. Figure 4).

Figure 4: Manipulation of Information Flow: (A) transferring data between two entities (B) changing the direction of the data flow using mirrors and (C) filtering and routing the data flow.

As an example, data can be stored on a set of daisy-chained SparKubes using an IrDA enhanced laptop. Once the data is uploaded to the cubes, the data bits per cube are mapped to a certain color (displayed using the LED per cube), as well as to the linear order the cubes are in. The stored information can be accessed by another IrDA enabled device by accessing the emitted light. The order of the information can now be mixed and therefore scrambled by removing or re-arranging a cube. To re-access the information, the original order of the cubes has to be restored.

CONCLUSION

We presented SparKubes, a set of tangible objects to explore the interaction space between digital and physical spaces. These stand-alone tangible objects are corded with simple behaviours and do not require additional instrumentation or setup. This goes beyond prior work that required e.g. to setup network connections or to instrument the environment. SparKubes only require to see each other in order to sense each other.

Central to SparKubes is the concept of accepting light from one direction, processing the encoded information, and then passing the light on to another direction. With optical transceivers on each side of the cube and integrated sensing capabilities, SparKubes support the manipulation of the information flow and both direct and indirect interactions. In addition, the transceivers can also be used to communicate with any device that supports IrDA (e.g. computers, smartphones). Unique to the overall concept is the integration with everyday physical objects such as mirrors to control the information flow. We depicted two salient SparKube applications to showcase the creation and manipulation of SparKube-based tangible interfaces.

As future work, we will evaluate SparKube as a play-based learning tool with pre-school kids. We believe that SparKubes can specifically make a contribution through tangible exploration of physical properties (i.e. light), as well as early exploration of computing paradigms such as windows, icon, mouse and pointer (WIMP).

REFERENCES

1. Ballagas, R., Ringel, M., Stone, M., and Borchers, J. istuff: A physical user interface toolkit for ubiquitous computing environments. In *Proc. CHI ’03*, ACM (2003), 537–544.
2. Coelho, M., Zigelbaum, J., and Kopin, J. Six-forty by four-eighty: The post-industrial design of computational materials. In *Proc. TEI ’11*, ACM (2011), 253–256.
3. Greenberg, S., and Fitchett, C. Phidgets: Easy development of physical interfaces through physical widgets. In *Proc. UIST ’01*, ACM (2001), 209–218.
4. Ishii, H., Fletcher, H. R., Lee, J., Choo, S., Berzowska, J., Wisneski, C., Cano, C., Hernandez, A., and Bulthaup, C. musicbottles. In *Proc. SIGGRAPH 99*, ACM (1999).
5. Ishii, H., and Ullmer, B. Tangible bits: Towards seamless interfaces between people, bits and atoms. In *Proc. CHI ’97*, ACM (1997), 234–241.
6. Lee, J., Kakehi, Y., and Naemura, T. Bloxels: Glowing blocks as volumetric pixels. In *Proc. SIGGRAPH ’09 Emerging Technologies*, ACM (2009), 5:1–5:1.
7. Merrill, D., Kalanithi, J., and Maes, P. Siftables: Towards sensor network user interfaces. In *Proc. TEI ’07*, ACM (2007), 75–78.
8. Pla, P., and Maes, P. Display blocks: A set of cubic displays for tangible, multi-perspective data exploration. In *Proc. TEI ’13*, ACM (2013), 307–314.
9. Raffle, H. S., Parkes, A. J., and Ishii, H. Topobo: A constructive assembly system with kinetic memory. In *Proc. CHI ’04*, ACM (2004), 647–654.
10. Villar, N., Scott, J., Hodges, S., Hammil, K., and Miller, C. .net gadgeteer: A platform for custom devices. In *Proc. Pervasive ’12*, Springer-Verlag (Berlin, Heidelberg, 2012), 216–233.
11. Zigelbaum, J., Kumpf, A., Vazquez, A., and Ishii, H. Slurp: Tangibility spatiality and an eyedropper. In *Proc. CHI EA ’08*, ACM (2008), 2565–2574.