A Display Cube as a Tangible User Interface

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ABSTRACT
In this paper we introduce the design and development of a display cube as a novel tangible user interface. Using the common shape of a cube we implemented a platform that supports input by gesture recognition and output through 6 displays mounted at the sides of the cube. Exploiting the physical affordances of the cube and augmenting it with embedded sensors and LCD displays, we enable different applications like a playful learning interface for children. Based on initial observations and users' experiences with the device, we argue that breaking conventions about how a computer has to look like and providing a playful interface is a promising approach to embed and integrate technology into people's everyday context and activities and enable new forms of interaction.

Keywords
Interactive Cube, Tangible User Interface, Ubiquitous Computing

THE CUBE AS INTERFACE
In this paper we present an enhanced cube as tangible user interface. The affordances of the cube as 3D object have been studied by Sheridan [1], suggesting a description of possible manipulations of the cube, based on action, description and events, that potentially provides a framework for the design of gesture based interaction techniques.

The engagement and playfulness afforded by the cube has already been exploited in several occasions: besides the popular Rubrik's Cube, or the simple dices, HCI research has looked at the cube as user interface. Zhi Ying et al. [2] explore the application of a foldable 3D Cube interface, complemented with augmented reality technology, to the field of interactive storytelling. Camarata et al. [3] use cubes as physical blocks to navigate a data space in a virtual museum, thus exploiting the everyday understanding of three-dimensional spatial relationship.

HARDWARE SETUP AND SOFTWARE CONTROL
To explore the use we have build a functional self-contained display cube, see figure 1. The current version of the cube is a 3D printout (made of epoxy resin) with 80mm edge length which has all the electronics and batteries inside. The central processing and wireless communication is based on a Particle Computers [4] which is a small wireless sensor node. The hardware of the node comprises a communication board integrating a PIC18F6720 microcontroller, a TR1001 transceiver for 125 kbit/s data transfer on the 868 MHz band, a real-time clock (RTC), additional 512KB Flash memory and two LEDs together with a small speaker for basic notification functionality. Running on a single 1.2V AAA rechargeable battery the board consumes on average 40mA with the communication and the LEDs active.

This main board can be extended with additional sensor and actuator boards. The cube specific hardware (display connections and sensing) is designed as an add-on board to the base platform, see [5] for detailed information including schematic, board layout, soldering instructions and part lists. On the website there is also the 3D layout in VRML that can be used to print the cube. The add-on board includes two accelerometers and connections for up to 6 displays. In comparison to [6] we opted for a self-contained setup to ease deployment and user test.

Input based on Gestures
Two two-axes accelerometers (ADXL311JE from Analog Devices) are orthogonally mounted inside the cube and are

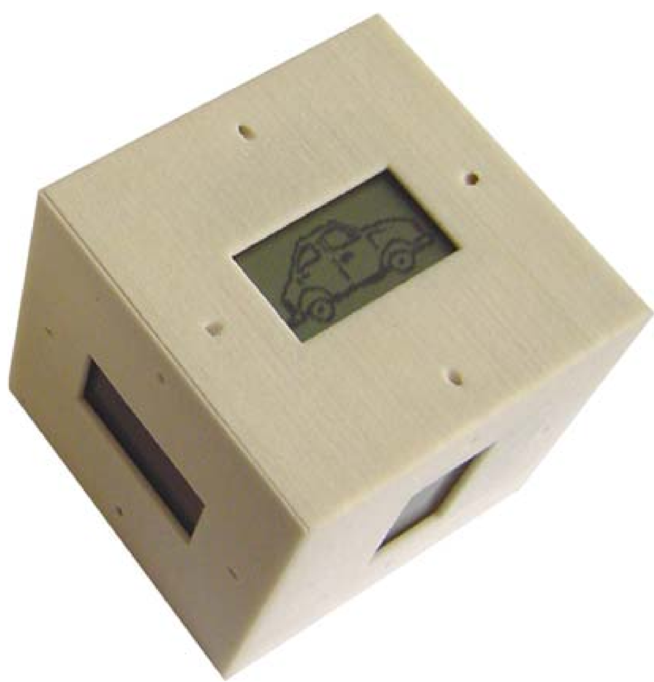

Figure 1: The completed tangible display cube showing a picture on the top display. The cube is a 3D printout.

the only means of input. They measure dynamic acceleration (e.g. vibration) as well as static acceleration (e.g. gravity) on two orthogonal axes, each. This means we have complete control over quick movements in 3D and can sense the rotational state, i.e. which display is on top. The last fact can be derived by a simple nearest-neighbor approach with the vector of the three acceleration values.

The Particle processor has proven to be powerful enough to apply algorithms that can detect several gestures made with the cube. This includes rotating, shaking and compound movements. A simple example of data related to gestures is

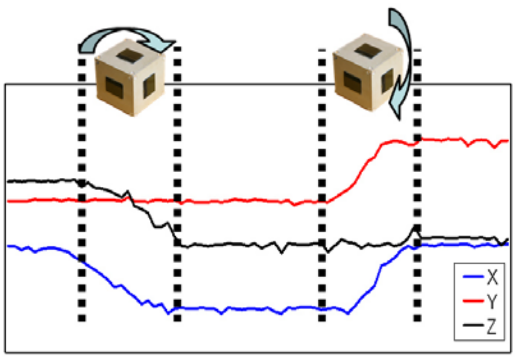

Figure 2: Acceleration data related to gestures.

shown in figure 2.

Visual Output

The add-on board includes driving electronics and connectors for up to 6 LCD displays that are controlled over I2C. In our prototype the Barton BT94060 displays with 96x40 pixels are used. Since the display is black and white only, one bit is enough to save the state of one pixel. A column of 8 pixels, located on top of each other, can then be expressed as one byte. This gives a total of 5 lines of 96 columns, i.e. bytes, each.

The only way to draw on such a display is to provide one byte at a time. This implies that to add, e.g., a line without destroying the existing drawing we have to buffer the contents of the display in software. One display needs 480 byte which accumulates to 2.8 kbytes for all 6. Since RAM is scarce, we opted for keeping only one display buffer in RAM memory and store the rest in the slower on-board flash memory. Loading an image with maximum size from flash memory into the display buffer and updating the display itself takes less than a second.

We support several graphic primitives like lines, rectangles and ellipses, besides text and arbitrary 1-bit images. Some basic operations like inverting the display are available and some more complex ones like text scrolling are currently under development.

APPLICATION AREAS

Conversion of 2D to 3D and v.v.: Orthogonal views are very common as representations of 3D objects in technical drawings. Imagine an object put in the cube. Orthogonal projections can now be guessed and verified with the images shown on the six faces. Or the other way round: given six images, how does the 3D object inside the cube look like?

Edutainment: Some tasks for smaller children that can be easily implemented: recognition of the same picture on different sides, a multiple-choice questionnaire, a word ↔ picture association, a vocabulary trainer, or matching multiple different 2D views. These applications build on the explorative affordance of the cube and on the design of a semantic link between physical control and digital output.

CURRENT AND FUTURE WORK

We are currently experimenting with different sizes and designs of cubes. An early version was made out of ply-wood. We changed now to a 3D print-out that was designed with a 3D design program. Printing the actual interaction object allows more flexibility and easier reproducibility of the system.

We have conducted initial user studies where an earlier version of the cube was used as a learning appliance, see [7]. In future work we will address further application domains and conduct a larger user study. One aim is to affirm initial results about the size and gestures with regard to the user experience.

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