Tangible UIs for Media Control – Probes Into the Design Space

Andreas Butz
University of Munich
Media Informatics
Amalienstrasse 17
80333 Munich, Germany
butz@ifi.lmu.de

Michael Schmitz
Saarland University
Computer Science
Stuhlsatzenhausweg Geb.36.1
66123 Saarbrücken, Germany
schmitz@cs.uni-sb.de

Antonio Krüger
Westfälische Wilhelms-Universität
Geoinformatics
Robert-Koch-Strasse 26-28
48149 Münster, Germany
antonio.krueger@uni-muenster.de

Harald Hullmann
Academy for Fine Arts and Design
Keplerstraße 3-5
66117 Saarbrücken, Germany
h.hullmann@hbks.uni-sb.de

CHI 2005, April 2–7, 2005, Portland, Oregon, USA.
ACM 1-59593-002-7/05/0004.

Abstract
In a student project over the summer of 2004 teams of computer science and product design students worked together to develop new forms of interfaces for media control in living room contexts. In this paper we describe the design process from collecting first ideas of design choices and iteratively evolving (low-fidelity) prototypes to fully functional products, partially even meeting mass production requirements. We discuss how the interdisciplinary collaboration influenced the creative process in such a way, that the solutions were more realistic than purely design-informed solutions and more inspired than purely technology-informed ones. We experienced that the combination of skills lead to a much more focused design process, which produced fully functional prototypes in a short time. The resulting designs include one interface installed in the room, two autonomous interaction objects which can be freely moved around, and a two-handed interface. While these are only small spotlights into a large design space, they nicely show the possible diversity. We also learned that fully functional and aesthetically pleasing prototypes can be developed with technologically relatively simple means.

Categories and Subject Descriptors
H.5.2 [User Interfaces]: Input devices and strategies

Keywords
Tangible User Interfaces, media control, interdisciplinary design, product design, interaction objects.

Industry/category
Academic research in HCI and product design

Project/problem statement
The project described here had the goal to bring together students from the fields of computer science and product design in order to learn successful cooperation in interdisciplinary teams. The task we set was to develop substantially novel types of interfaces for a well-known task from our daily living environments. In order to provide inspiration and background, we introduced the students briefly to existing work in the field of tangible user interfaces. In an initial discussion phase, the majority of the students narrowed the originally very broad topic down to the task of building tangible user interfaces for media control in a living room environment, partially because this seemed easy to simulate with standard PCs. Here we will report on the design process and the results of these students.

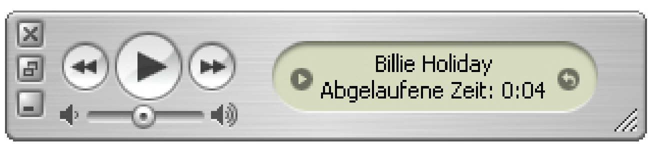


Figure 1: A basic UI for media control as we know it (iTunes).

For students of product design it is important to learn how to find new forms and shapes as well as basic concepts for interactive or non-interactive products. They learn how to prototype, evaluate and refine the formal aspects of their designs at various levels, starting from sketches in the initial process of form finding over volume models up to computer-aided designs which specify not only shape, material, and visual appearance, but also details of the production process, such as grooves and rabbets and how to shape plastic parts, such that they can be produced by die-casting machines. If these products are envisioned to offer functionality beyond mechanics, this functionality is mostly left out in the prototyping process and only described or sketched.

For computer science students, this situation is almost exactly the inverse. They might be familiar with building and programming electronic devices, and if they attended HCI classes, they will also be familiar with various levels of prototyping interactive software systems for use on a computer screen, but the mechanical aspects of computing or media devices are mostly accepted as they are or considered something “the designers will do later”.

In our project we hoped to bridge these two worlds and to achieve a design process, which is informed from both sides. While the product design students could still do their original work of finding and developing forms and shapes, they received permanent feedback about how well their designs were suited to being turned into a functional prototype with the technology at hand. They learned to pay attention to this aspect early in their designs. Conversely, the computer science students learned a lot about the restrictions implied by mechanical design and were forced to be more creative in their choice of technology. We expected that the emerging designs would gain substantially from this constant dialog between the free flow of ideas and the necessity to produce a fully functional prototype in the end. As for the students, we hoped that by learning about the other discipline’s problems and methods, they would develop a better understanding and ability to put their own work in perspective when working in interdisciplinary teams.

Background/Project participants

The project was taken by second and third year design students and by third and fourth year computer science students. They were advised by one faculty member and one researcher/lecturer from each department. The students formed groups of two product designers and two computer scientists, and each group worked on two different designs in parallel. For the design students, this was their first major design project, which at the same time represented a substantial part of their bachelor’s degree. For the computer scientists, the project was the first autonomous development project and had a similar importance in their course of study. In contrast to earlier experiences with interdisciplinary projects, all students who started this project also finished it with good results.

“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.”

Mark Weiser: “The Computer for the 21st Century”

Project dates and duration

The project was scheduled over the summer semester of 2004. The kick-off meeting took place in the last week of April and in weekly plenary meetings, intermediate results were discussed until the end of July. The final presentation of functional prototypes and submission of the documentation materials ended the project in mid October. Between the meetings, students could use a design atelier at the Saarbrücken Academy for Fine Arts and Design with facilities for computer-aided design, construction and manufacturing of objects from various materials. They were also provided with facilities for the construction of simple electronic circuits including a soldering station, power supplies, metering facilities and a number of ready-made components at Saarland University. Students worked almost full time on this project over half a year, giving lower priority to other classes during the semester.

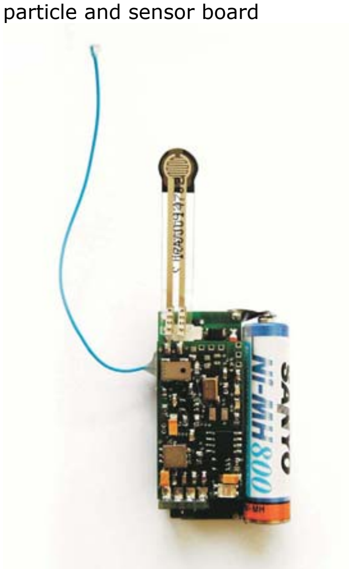
Challenge

The main challenge was to find radically new forms of user interfaces for the very well-known task of media (more specifically CD or MP3) control in a living room setting and, within a short time, build working prototypes of these. Current UIs of HiFi equipment almost exclusively use buttons, knobs, dials, lights and character displays on the main unit which might follow visually new design concepts at best. Their basic operation remained the same for the last decades. Even less imaginative are the widely used infrared remote controls featuring rubber pushbuttons. The students were asked to think of new and potentially decorative form factors for control interfaces, which would weave themselves into the fabric of the living room. The designs had to be transformed into a functional prototype and presented at the end of the semester. While this presented enough technical problems on both sides, the main intended learning effect was the successful work in interdisciplinary teams. The tight schedule on the other hand left no time for a real user evaluation. Usability aspects were therefore explicitly considered secondary to finding new form factors.

Solution summary

The students started from a very broad definition of the problem space and, in discussions, successively narrowed it down to finally formulate more specific ideas how the problem could be approached. The first group decided to integrate a device for media control into the environment like a piece of furniture or a lamp.

A combined Smart-It particle and sensor board



Their first idea was a set of strands or twines hanging from a kind of chandelier. This idea gave their project the name “hanging twines”, and even though the original concept changed quite a lot in the process, the name remained. Two other groups decided to build a single interactive object, which users could handle freely and which would assume a decorative function in the living environment. Their solutions will be described in detail under the names of “Flower” and “Pyramid Control”. One group finally decided to design not only one object, but two, which would complement each other for two-handed interaction. Since one object turned out to be cubic and the other one cylindrical in shape, their prototype was called “Flip’n Twist” after its primary types of interaction. Sketches were made of the initial ideas, and in an iterative process, the basic concept was refined and flaws and weaknesses discovered. This refinement process involved a very tight cooperation between the design and the computer science students, since the physical shape of objects restricted the kind of electronics, which could be built into them, and vice versa. Intermediate results were presented and discussed in bi-weekly plenary meetings. At the end of this phase, the students produced a moderately detailed technical sketch of a seemingly viable solution at the scale of 1:1. The next major step was to transform these 2D sketches into styrofoam volume models, where appropriate. With these models, additional construction issues could be clarified, interaction could be simulated and the interaction concept was informally tested and refined. In parallel, the computer science students developed the technical parts of the intended devices. While we had provided Smart-Its particle computers [1] with a range of sensors and a radio connection to a host PC for their convenience, half of the groups decided to rather use other sensing hardware, because it seemed more appropriate for the task. Starting from the volume models, students had to determine how the physical designs could be built from milled plastic parts and how they could produce the final physical prototypes, into which the computer science students integrated their electronics. In a final presentation event, all groups presented their solutions and gave a demo of the devices in operation.

Solution details

Hanging Twines

The first group consisted of one product design student and one computer science student with a strong electronics background. In an initial discussion they agreed to aim for an object, which would be part of the environment, almost like a piece of furniture or a lamp. They developed several ideas, which eventually lead to the concept of a chandelier-like installation, which would hang from the ceiling (figure 2).

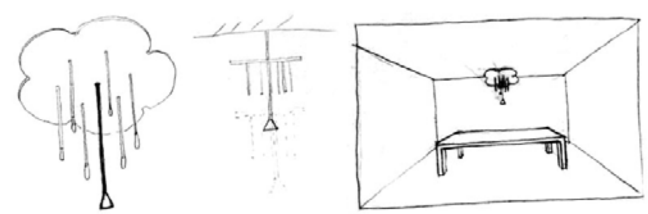


Figure 2: A chandelier-like installation with twines for pulling

This initial idea was then refined and it was found that some form of feedback was needed. In consistency with the chandelier concept, visual feedback in the form of colored light seemed appropriate.

Mechanical construction of the hanging twines device

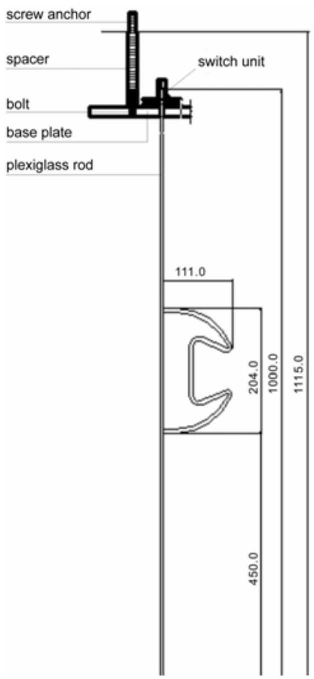


Figure 3: Variations of the chandelier emitting different light

Plexiglass rods were chosen as the material for the twines with the plan to illuminate them from the top end and thereby achieve luminosity over the whole length of the twine. The ends of the rods were designed to provide affordances [2,3] or at least visual invitations for pulling and/or turning.

Figure 4: Differently shaped ends of the rods providing affordances for turning, pulling and turning, or just pulling

It was argued that users would feel much more compelled to pull a rod which had a knob in the end and that they'd rather turn a knob with a thicker diameter and a colored lagging. Knobs providing both interactions thus featured both the knob and the lagging. While the initial concept contained variable light colors, after some trials in daylight the students found out that sufficiently strong multi-colored LEDs were not available. So the concept was simplified to a single light color per rod. In the ongoing design iterations, also the spatial arrangement of the rods was changed to be linear, since this would provide a clearer visibility of control options. Since the plexiglass rods could be bent and formed in almost arbitrary shapes without losing their conductivity for light, it was proposed to shape the rods in such a way, that they would reveal their functionality by a similarity of their shape to the conventional symbols for media control, such as play, pause, forward, rewind and stop.

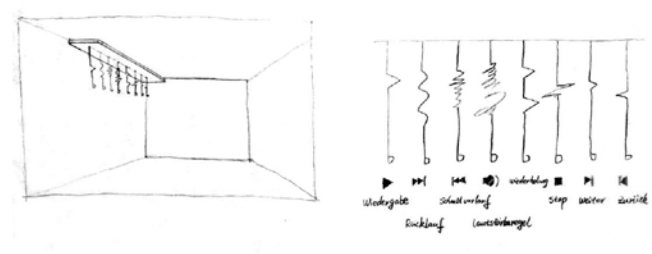


Figure 5: linear arrangement of rods in different shapes

A set of shapes was developed and the rods were formed according to these shapes. Now that they had lost their rotational symmetry, it turned out that they could be conveniently used for multiple functions: Since the symbols for rewind and fast forward are the same, just mirrored, one rod was sufficient, depending on its orientation, to signal both functions.

In the beginning of the project, the computer science student had the idea of controlling HiFi equipment via infrared output from a computer. In one of the project discussions, this concept was turned around and the student decided to take apart a programmable IR remote control and connect micro switches in the base plate of the twines device to the keys of the remote control. Thereby, pulling a rod or turning it to a given position would trigger the remote control to send a signal. Since the remote control was programmable, it could be trained to control any given HiFi device. The final prototype was therefore fully functional with any home entertainment device, just by creatively using off-the-shelf hardware.

Figure 6: The final prototype of the hanging twines

An infrared receiver on a PC also received the IR signal from the remote control, and a program controlled the LEDs of the twine device for visual feedback. Rods for play, pause, or stop would just light up to signal their activity and a more playful form of visual feedback was provided by lighting the rods up in a sequence in the respective direction during rewind and fast forward in order to visually mimic these activities.

Pyramid Control

The second team also consisted of one product design and one computer science student. They started to find concept ideas by trying to merge their interests and skills, which unfolded during their first meetings: The product designer wanted to create a singular device which could be freely placed in a living room and the computer science student had the goal to remotely control a desktop media application by physical manipulation of an interface object. During the first phase of the project they decided to build a stationary but movable tangible user interface controlling a MP3 player application residing on a regular desktop PC. They also determined further requirements at this stage before starting with the actual concept design: The device should - of course - be visually appealing and function wirelessly such that it could be freely placed anywhere in the living room according to the users' practical and aesthetical preferences. On the technical side, the students decided to make use of Smart-Its devices for detection of the object's state instead of constructing their own hardware from scratch. Although the use of such integrated hardware might limit the design choices, Smart-Its with their variety of sensors and communication abilities offer a high degree of flexibility for developers as outlined later in this chapter.

From these specifications, a first rough concept was developed involving several movable components of one object, each of which contained a Smart-Its device detecting its relative position to the main body. Some first design ideas were shown in the sketches in figure 7.

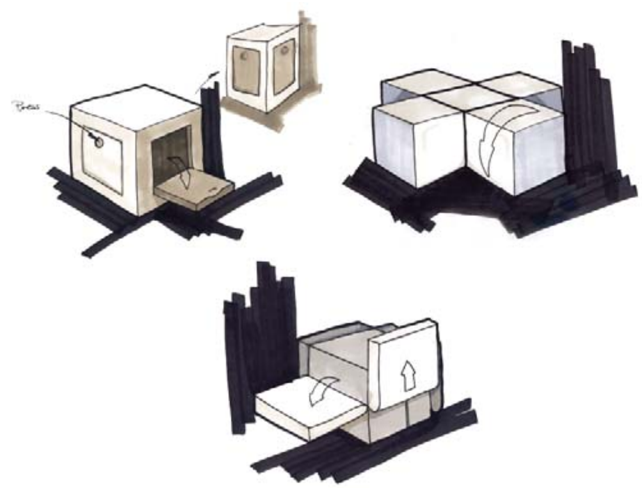


Figure 7: Some first conceptual sketches of the device

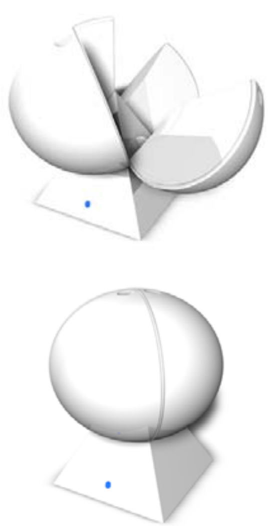
This set of first drafts was studied considering their visual appearance, affordances and technical implications to narrow down the choices and directions in which to continue. The students found the concept of having *wings* most interesting, i.e. four elements that could be tilted up and down, symmetrically arranged around or standing on a base.

Now the product designer continued to adjust the form of the object, removing prominent edges and angles to have a softer and rounder appearance. Furthermore each wing needed to be able to contain one Smart-Its device imposing requirements on its minimum dimensions. These considerations lead to the next stage of the design, a pyramid-like device. Some early form prototypes made of styrofoam can be seen in figure 8.

Figure 8: Styrofoam form prototypes

The construction of actual prototypes lessened the level of abstraction of the previous sketches and provided a much better impression of the object's appearance and presence. At this point, the basic configuration was set as some kind of foldable device allowing direct manipulation of player functions by adjusting the movable parts - giving an additional visual feedback of the system state by the current wing positions. While at this stage the product designer worked on different shapes, the computer science student started to experiment with a Lego prototype (figure 9) to analyze sensor data and start with programming. Also in this group, the shapes found early on gave the device its name, and although the final prototype had a totally different shape, this name persisted.

3D models of the prototype:



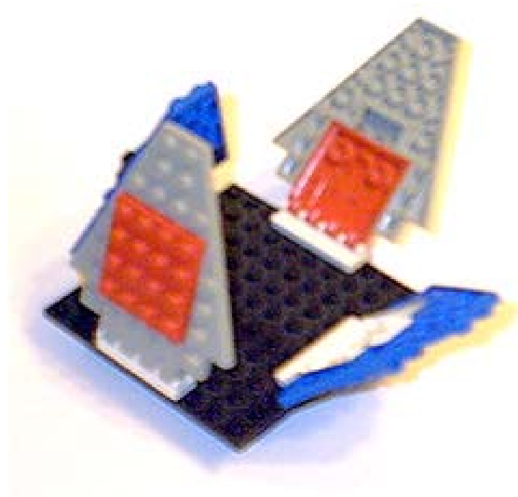


Figure 9: The Lego model of the pyramid

The acceleration sensors of the Smart-Its are configured to continuously send their data over a radio link to a receiver in the vicinity (up to 10 meters) which in turn is connected to a PC running the application being built. This application evaluates the sensor data to determine the positions of the wings and to activate functions of the player accordingly. The usage of Smart-Its had the advantage that it was not necessary to have much knowledge of electrical engineering basics or practical experience with circuit building. Furthermore they freed the student from the burden of dealing with wireless communication, since the Smart-Its system takes care of it. This potentially leads to fast prototyping and early results, once the developer is acquainted with the tools of the Smart-Its infrastructure. However, using acceleration sensors is not the ideal way to obtain the wing position in such a setup. Tilt sensors would have been much more straightforward. Relatively small movements must be extracted to infer the current position, while the incoming data happens to be quite noisy on such a small scale. Although this required more work on the algorithms, this solution seemed still more desirable for the computer science student than to study low level hardware design and construction. The student solved his task by programming a library, which allows the mapping of wing configurations of the device to arbitrary DLL-functions and their parameters, providing a quite flexible tool for this device. One instance of the prototype was implemented to control basic operations of the WinAmp Media Player [4].

After a couple of iterations and form prototypes the device was finally completed (figure 10).

Figure 10: The final prototype

A sphere consisting of four parts resides on a stand with a LED indicating the front side of the device. The LED should face the user, such that the spatial mapping of the wings makes sense. In its initial closed position the dividers of the movable parts indicate the partitioning and, in conjunction with a small cavity on top of each wing, suggest the possible interaction.

Different mappings of functions to configurations of the device were informally tested with students until the mapping in figure 11 (as seen from below) was chosen, which turned out to be learned and remembered easily.

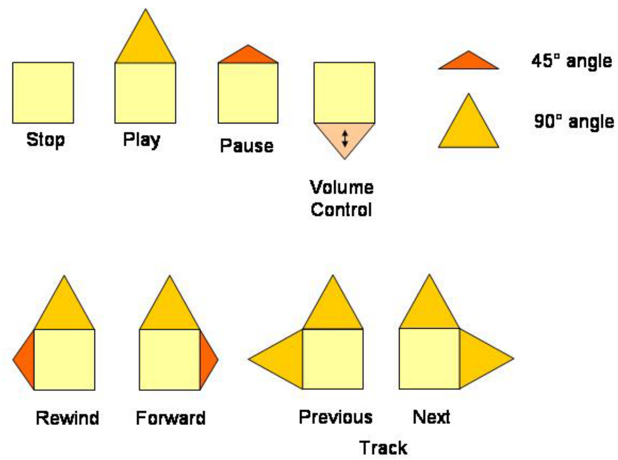


Figure 11: Mapping from device parts to functionality

A closed object means stop, pulling the front side down starts playing, while half-way down (45°) pauses the playback. The backside directly controls the volume by its position whereby closing this side means 'mute'. The left and right wings rewind and forward respectively when pulled down half-way while by tilting them down further tracks are skipped in the according direction.

Flower

The third team (consisting of one designer and two computer scientists) initially developed a very similar solution to the "Pyramid Control" group, but made different implementation and design choices on the way: The students initially decided to build a simplistic and generic interface for the control of household appliances in general, which can be placed anywhere in the house, e.g. on a table or shelf, without requiring to wire the device. In this case the product designer took the lead in the phase of finding a general concept, while the computer scientist merely reacted to suggestions by evaluating the technical feasibility of the implementation and applying restrictions on design solutions for the next iteration step. The students decided to create a device composed of *layers*, each of which holds buttons or switches mapped to logical layers of a structured set of controls. Some first design ideas went in the direction of an onion-shaped device, which can be 'peeled' to activate functions (figure 12).

Figure 12: First form prototype

When this concept was turned into a form prototype, it became obvious that integrating the hardware to detect the positions of the movable parts in such a setup would probably be very difficult. Therefore, adjustments to the form were made towards a more static device with levers (figure 13).

Figure 13: More variations of the form prototype

The computer science student decided to build the circuitry from scratch instead of using external solutions such as the Smart-Its, to be more flexible during the form finding stage. Hence, the onion evolved to a flower. The computer science student used a simple prototype (figure 14) with approximate dimensions of the final version to start building and testing the electronics at this point, while the product designer continued working on design issues.

Two switches were connected to each petal to detect up- and downward movements, returning a soft click as feedback. The student used the interiors of an off-the-shelf infrared remote control to facilitate communication with either a receiver connected to a PC or directly with a common multimedia device such as a CD player. Each button sends a signal to a controller chip when it is pressed and the controller chip encodes the state into an infrared signal and activates the diode to transmit it until the button is released. The receiving counterpart decodes the signal and triggers the appropriate function of the presentation device or application. The IR receiver connected to a PC decodes the signal and sends the information over a serial link to a service on the PC.

Figure 14: Functional model for first hardware integration

For the demonstration scenario the students connected a miniature house made of Lego to the parallel port, such that their device is used to switch on/off different lights and open/close blinds. Using infrared as the communication medium implies that line of sight to the receiver must be given, restricting the choice of the device's position in the living room, but keeping the hardware costs very low.

Figure 15: Later versions of the form model

The product designer iteratively produced form prototypes, keeping the conditions of basic sizes and arrangements previously agreed with the computer scientist. The final version emphasizes and distinguishes the three different layers stronger than its predecessors and indicates more clearly that each petal can be moved up and down (figure 16).

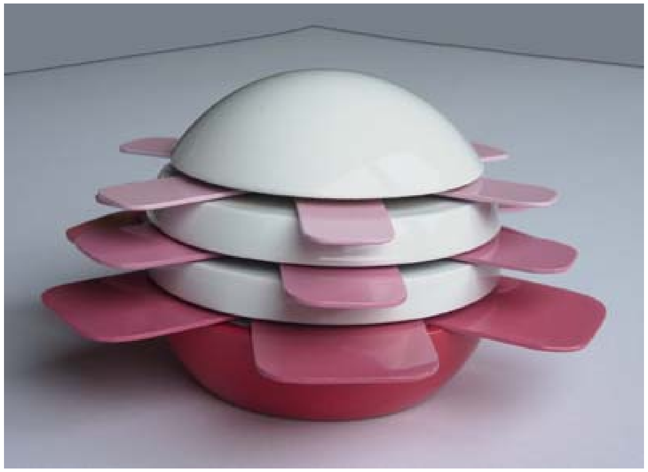


Figure 16: Final prototype of the flower device

Since the assignment of the petals are variable the students created symbols to be drawn on top of each petal to denote the attached function, but they did not apply them to the demonstration prototype.

The object generally reflects the logical structure of layers. In the household demo, these were different physical layers of the house: outer petals controlled the outer window blinds, while inner petals controlled inner devices, such as room lights. The object can also be used to control logical layers. In the demo case of media control, the outer layer could, for example, control overall volume or sound processing, the middle layer could switch between components of a HiFi system, while the inner part controls playback on a single component.

Flip'n'Twist

The fourth team again consisted of one computer science and one product design student. Similarly to the other teams, the role of the computer science student in the conceptual phase was to provide technical knowledge and explain the constraints given by technology, while the product design student was responsible for developing a general approach and for sketching the design studies.

Figure 17: A styrofoam prototype of the first cubical device with labels for operational modes and a first version of the second device with a dial-like shape

During the implementation of the prototype the product designer worked on the physical appearance and the mechanics, while the computer scientist was responsible for the integration of the Smart-Its hardware and the software for the evaluation of sensors and logistics of the interface. During the discussions in this initial conceptual phase, the students decided to design a remote control for HiFi-components, which would differ from traditional remote controls in two aspects.

Figure 18: The final prototype, which allows one-handed operation without a planar surface

The first aspect was the choice of a simple physical form for the device. The second aspect was the radical reduction of the number of buttons in comparison with an ordinary remote control. To achieve these goals, the group targeted at a bimanual device, consisting of two different parts, which could be used separately. To decide on the form issue, several related concepts were inspected [5,6,7], which all based on the form factor of a cube and promoted the idea of using a cube as well. Figure 17 depicts one of the first styrofoam prototypes of the device, which is already close to the final version. Given its six faces a cube can be used to select six discrete options, which is per se not enough to control complex media equipment. The second device allows users to input continuous data, for example, to control the volume or do a fast search through songs on a CD.

Figure 19: The final prototype of the cubical device, without labels for operational modes

In analogy to a jog dial, the first idea was to use a circular shape, such as the one shown on the right in figure 17, which could be used like a dial. After some discussion, both technical and usability drawbacks were identified. On the technical side, the acceleration sensors used in the smart-its platform were not reliable enough to recognize small changes as a result of small or quick turn operations. On the usability side, this design would have made it necessary to use both the dial and the cube on a table, which makes them unusable in a more comfortable position in an armchair or on the sofa. Both problems were solved by designing the twisting device in such a way, that it can easily be held and operated in one hand. The final solution for the second device has a cylindrical form and consists of a main body and a rotating upper part which can be twisted or spun with the thumb as shown in figure 18. A high-precision potentiometer without stop position was used to sense the turn operations, regardless of the orientation of the device. As shown in figure 18 and 19, the color and appearance of the cube and the cylinder were harmonized to express their togetherness. Interaction with the two devices is straightforward. The cube is used to set the system into the desired operation mode. The different modes can be selected by flipping the cube from side to side, where the selected mode faces up. One typical example is to flip the cube until the upper face displays the symbol for volume adjustment. The exact sound level is then selected by twisting the second device. Although the twisting device was designed explicitly to input continuous data, such as volume, it can also be used to make choices or a binary decision by left or right turns. This helps for example to implement functionalities provided by traditional remote controls for HiFi-equipment, e.g. skipping or repetition of the current song. While the cube is restricted to be used on a planar surface for correct orientation detection, the twisting device can be used in any position, e.g., comfortably from the sofa. The combination of the cube and the twisting device allowed seven discrete selections (skip song, repeat song, play, pause, stop and shuffle) and four continuous selections (speed of fast forward, speed of rewind, increase volume, decrease volume).

In the prototype installation (figure 20) the cube and the twisting device were used to control a media player on a personal computer. Smart-Its were used to send input data from the devices to the computer. One Smart-It was used to sense the orientation of the cube and another one in the twisting device to sense rotation from the potentiometer.

Figure 20: The setup of the prototype.

Results

The designs presented in the previous section represent several spotlights into the design space of tangible UIs for media control. While they are far from an exhaustive exploration of this design space, they nicely show how diverse the solutions for such a relatively simple task can be. All groups provided a working prototype, which controlled a real media player or HiFi device and was mechanically constructed in a way suitable for mass production (i.e., die-casting etc.). Real mass products, would, of course, have to undergo careful evaluation and user tests during the whole design process. The designs presented here were only discussed with and informally tested by teachers and other students. This can at best be seen as a very lightweight form of quick-and-dirty evaluation. One reason for this lack of user testing was the fact, that the form finding process took relatively long and that testable prototypes were only built relatively late in the project. When the whole project is repeated, the importance of user testing will be emphasized much more.

Nevertheless, we think that our initial assumption, that a design process informed from two sides would be much more efficient, was met. In the course of this project, we also learned a number of things about the way in which students approach such a broad topic. The computer science students seemed to be very eager to arrive at a very concrete level in their concepts quite early. This became apparent in the fact, that almost all teams had already found names for their projects in the second meeting. While the designs evolved, the names remained and in some cases were relatively inadequate in the end. The product design students, on the other hand, exhibited a tendency to remain much more vague in their designs. They avoided narrowing down the design space too early, which also allowed substantial redesigns relatively late in the process. Once the physical volume models were built, and one of them was agreed on, this tendency disappeared in favor of the work on details, such as coloring, materials and surfaces.

Another insight was the following: When product designers have to collaborate with practitioners of other disciplines a typical conflict often arises: Since everybody makes creative and sometimes artistic decisions in different situations of their private life, most people assume to have some basic expertise in the field of design and try to position their ideas. It was therefore helpful to let the computer scientist take part in meetings and discussions of the product designers to make their design process transparent and to show the context in which professional design emerges and develops. In the other direction, designers often tend to oversimplify technical aspects and make improper assumptions about what technology can do and what it can't. Exposing design students to the practical building of specialized hardware, if even at the level of a toolkit such as the Smart-Its, enhanced their ability to judge feasibility and to communicate technical requirements.

The choice of Smart-Its as a given infrastructure for sensing appeared logical to the teachers in the beginning of the project. Having worked with these devices before, it seemed natural that they were a good vehicle for rapid prototyping. In contrast to that, the students found it relatively hard and tiring to learn about microcontroller programming if all they wanted was to detect the push of a button. Half of them therefore refrained from using the particle boards and turned to other off-the-shelf hardware. Although one group even started their proper hardware design in the beginning, this was given up later on in the project in favor of a modified remote control. If we were to do a similar project again, we would give more freedom of choice regarding hardware right from the beginning and also discuss obvious alternatives provided by hacking available hardware.

Acknowledgements

We thank all the students who participated in the project and in particular those who built the devices described in this article. They are: Yanfei Sun, Paul Boeßhar (hanging twines), Norbert Bartels, Esther Hechler (pyramid control), Luise Becker, Michael Raber, Thomas Maurer (flower), Dominique Taffin, Jan Hilt (flip'n twist). Eight more students took part in the project and contributed to all discussions. Their designs were only excluded because they departed from the narrower theme of this article (media control), not as a judgment of the quality of their work.

References

[1] Beigl, M. and Gellersen, H.-W. Smart-Its: An embedded platform for Smart Objects. Proceedings of Smart Objects Conference 2003 (Grenoble, France, May 2003)

[2] Gibson, J. J. The Theory of Affordances. In R. E. Shaw & J. Bransford (eds.) Perceiving, Acting, and Knowing. Lawrence Erlbaum Associates, Hillsdale, NJ, 1977.

[3] Norman, D. Affordance Conventions, and Design. Interactions 6, 1999, ACM, 38–43.

[4] Nullsoft Inc. The WinAmp MP3 Player http://www.winamp.com/

[5] Rekimoto, J. and Sciammarella, E. ToolStone: Effective Use of the Physical Manipulation Vocabularies of Input Devices, Proc. of UIST 2000, ACM press 2000.

[6] Fitzmaurice, G., Ishii, H., Buxton, W. Bricks: Laying the foundations for graspable user interfaces. Proceedings of CHI'95. pp. 432-449. New York: ACM Press 1995.

[7] Block, F., Schmidt, A., Villar, N., Gellersen, H.-W. Towards a Playful User Interface for Home Entertainment Systems. EUSAI 2004. LNCS 3295, pp. 207-217, Springer, 2004.