Post Desktop User Interfaces
Actuation

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ABSTRACT

When we think of interaction with common desktop computer systems today, we usually think of a Graphical User Interface (GUI) operated with keyboard and mouse. In this paper we want to introduce the reader to a much more physical form of interaction, allowing the user to directly interact with physical representations of digital objects.

Author Keywords

Actuation, Post Desktop User Interfaces, Tangible User Interfaces

INTRODUCTION

As the title of this paper suggests, the main topic of this paper is actuation. However, we feel that Tangible User Interfaces (TUIs) are important to the understanding of this topic as they represent an input method that is, in many ways, comparable to the way actuation provides feedback to the user. Tangible user interfaces enable the user to influence digital objects by moving and shaping physical objects, thereby creating an input method with a more direct feel to it. This principle of direct, physical interaction can also be reversed: actuation can deliver physical feedback to the user and change physical objects to account for the changes of digital objects. Furthermore, many technologies that implement tangible user interfaces can be improved heavily by introducing actuation into the equation. Therefore, we will use the first section of this paper to briefly introduce the basic concepts of tangible user interfaces and give two examples of such interfaces. Afterwards, we will focus on the main topic of this paper, which will be actuation.

Tangible User Interfaces

The basic idea behind tangible user interfaces is to enable the user to directly interact with digital objects instead of using rather indirect means like the mouse or other more commonly distributed tools. This has several advantages: Controls that are actually physically graspable allow the user to also use his tactile sense, adding yet another layer of information to the experience of interacting with a computer.

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Since TUIs do not need to completely rely on a graphical user interface, they also allow for a more intuitive, under some circumstances even blind operation. To achieve this, representations of the digital objects are created in the real world and equipped with sensors to establish a connection between the objects and the computer. When one thinks of the usual desktop environment, this appears to be a tedious task: creating physical representations of all the objects the typical user interacts with on a daily basis is next to impossible and would definitely be very expensive. Therefore, projects that work on the development of TUIs have specialized on specific tasks or used generalized objects to create control elements that are applicable for a number of different situations. In the following we want to introduce two of those projects.

Illuminating Clay

This project aims to connect two important steps in the practice of landscape architecture: clay and other physical media are used to create first raw models of the landscape the architect has in mind. After that, the vision of the architect needs to be thoroughly tested in different numerical simulations, which are usually done with the aid of a computer. This creates a gap between the first designing process and the next iteration of the design: Since the architect first needs to run several simulations, the model needs to be digitalized in some way and can only then be tested. After the simulations are done, the next iteration can be created and the process can start again.

Illuminating Clay uses the clay model as a direct interface: The architect can sculpt the landscape out of clay while a computer captures and analyzes the geometry of the clay model with a laser scanner from above the model (figure 1). The project also adds an projector above the model, so the data from numerical simulations can be directly projected onto the model while the architect works on it. This allows for a much more efficient approach to the design process since changes in the model can be seen in context with the simulations, closing the gap between the two steps mentioned above [15].

SLAP: Silicone Illuminated Active Peripherals

While Illuminating Clay took the approach of working on a specialized solution for a certain use case, the SLAP-Project takes a more general approach to making user interfaces tangible. SLAP introduces several tangible widgets made of silicone that can be used on multi-touch tabletops. The wid-

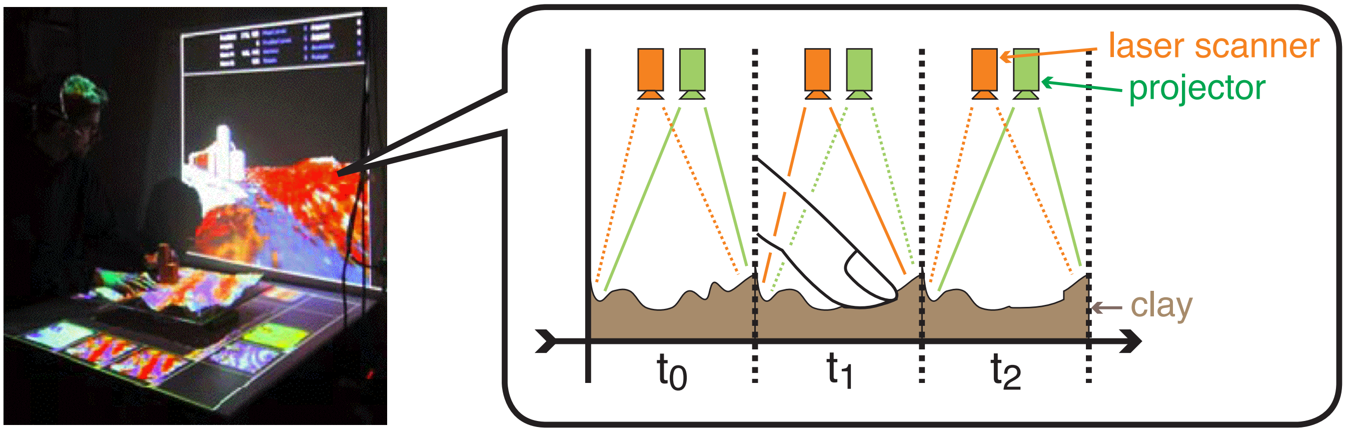

Figure 1. Illuminating Clay: A landscape model made of clay with a projected image on its surface at time t_0 can be manually modified (t_1). The modifications are captured by a laser scanner. The simulation is then actualized and the projected image accordingly adapted at the time t_2 as feedback for the user [15].

gets are detected by a camera that is positioned below the table and tracks the movement of the widgets. Those widgets include buttons, knobs and sliders and even a keyboard, which can be put on multi-touch tables and create tangible controls for virtual counterparts which could only be used via the touchscreen before. Since the widgets are made of acrylic and silicone, the user can see through them, which enables the screen of the tabletop to provide additional information to the controls (figure 2).

The tangible control offered by the widgets has certain advantages over the touchscreen-controls: The user can operate them without looking on the screen, which is especially important using a keyboard: users have problems to blindly operate an on-screen keyboard, simply because there is no tactile feedback to a button-press [15].

But there are also disadvantages in the usage of those widgets: In a multi-touch tabletop environment, the graphical user interface can easily be changed to account for a new situation or a different use case. However, if physical widgets are attached to the screen, those widgets will lose their context if the GUI is changed: Where there was a slider before, there might now be a virtual button or no control element at all. However, this problem can be addressed by adding actuation, as we will see in a later section of this paper.

ACTUATION

Just like TUIs enabled the user to use objects in the real world for input in the digital realm, Actuation aims to deliver output in the form of physical feedback of events in the digital realm to the real world. As we have seen in our description of the SLAP-Project, TUIs do have certain problems when it comes to the consistency between the physical and the digital representation of an object. When the user moves a physical switch, this motion is tracked by the camera below the table, which makes it possible to translate this action to the digital representation of the switch or the value that is being controlled by the switch. But what happens if some other event changes this value? The switch will still stay in the same position it was before, therefore creating an inconsistency as long as the user does not choose to man-

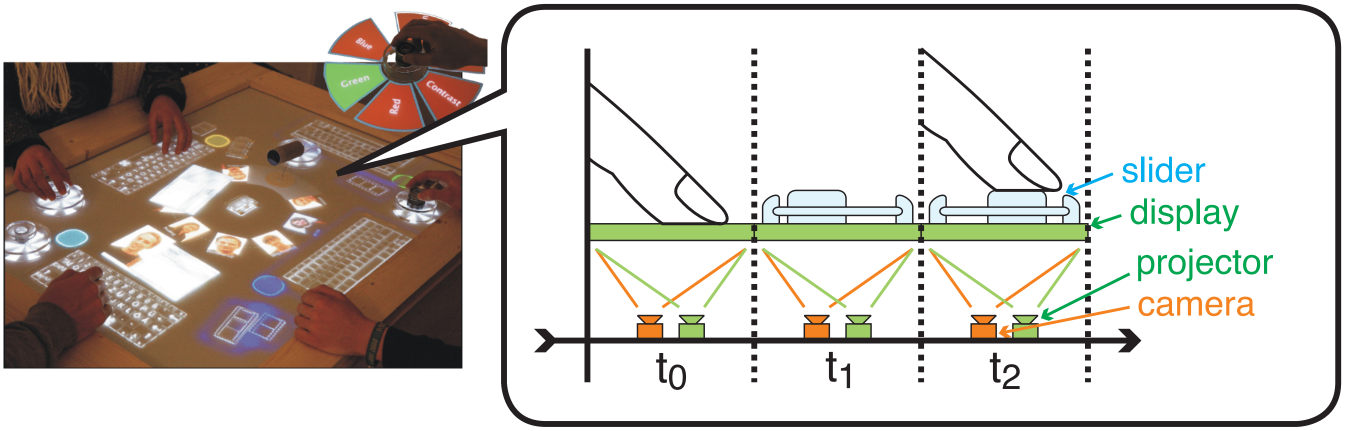

Figure 2. SLAP: With an infrared camera below the screen both direct fingertip position as seen in t_0 and positions of - for example - an acrylic slider (t_1) can be detected. This slider itself on the other hand can moved by the user as input device. The state of this input device is also detected by the camera (t_2) [15].

ually correct it. As we have seen, a very similar problem occurs if the context of the interaction is changed: In the underlying tabletop GUI, the positioning of buttons or switches might have changed, but the physical elements of the user interface were not changed at all, creating yet more inconsistencies. This forces the user of such interfaces to stop in his working process and realign the control elements, hence interfering with the work flow of the user. Since this is obviously not a desirable behavior of a user interface, a technology that can actually influence control elements in the real world is necessary. Actuation aims to solve this problem by giving the developers of interactive systems different tools to project changes in the digital realm onto the real world and make them graspable. There are a lot of different ways to give the user feedback on digital objects and we want to present a few chosen examples in this paper.

Actuated computer output can be generated in a number of different ways, depending on the type of desired output. In the next section of this paper, we will introduce some of those methods. Haptic feedback on a touchscreen, for example to simulate real buttons, can be achieved without producing real changes in the surface structure. Instead, the feel of the surface can be modified.

Surface Texture

While a keyboard gives haptic feedback, and the user can feel the edges of the buttons, a touchscreen with its virtual buttons lacks this helpful feature for blind typing. Especially for devices which might need to be operated without the users full attention (e.g. mobile phones and peripheral devices in automobiles), additional feedback supporting the graphical user interface is necessary. While audible feedback provides a good supplement [2], haptic feedback can provide further support in situations where audible feedback is not applicable, for example areas with loud background noise..

For these basic haptic functions no surface relief modification is needed. Instead, a changeable surface texture can fulfill those needs. Texture change can be achieved in different ways. We will present three different examples of such technology in the following section.

Vibration devices

The vibration of piezo-elements (like the vibration alarm of a mobile phone) can be used as haptic feedback for the user input. Changing the frequency and volume allows different feedback types, according to the fingertip position on the touchpad. For example, as described by Nashel and Razzque [14], placing the fingertip on a non-button-region will result in no vibration, while moving the finger closer to a button leads to a vibration with low amplitude, which will be increased when the button is actually pressed (figure 3). This enables the user to blindly search for a button on a touchscreen, just like he would on a physical control panel, when other events need his visual attention.

This device uses only technology which is already employed in nearly every mobile phone on the market and many other mobile devices (i.e. vibration motors). However, it does not scale up for multi-touch, because in most mobile phones today, there is only one vibration motor. Directed haptic output, like a movement of the vibration from top to bottom, is not possible, either. Another project, SemFeel [11], addresses this issue. Here, an array of five vibration devices is used to produce directed output.

If an array consisting of more vibration devices is used, an individual response to the different pressure points of a multi-touch input is also possible by dividing the screen in regions according to the individual vibration devices.

TeslaTouch

The next version of texture modifying devices we will present in this paper is the TeslaTouch [16]. As shown in figure 4 the user feels friction according to an electrostatic charge as his fingertip moves over the touchscreen. The electrostatic charge can be changed according to the finger position similar to the last technology we've discussed. Different fre-

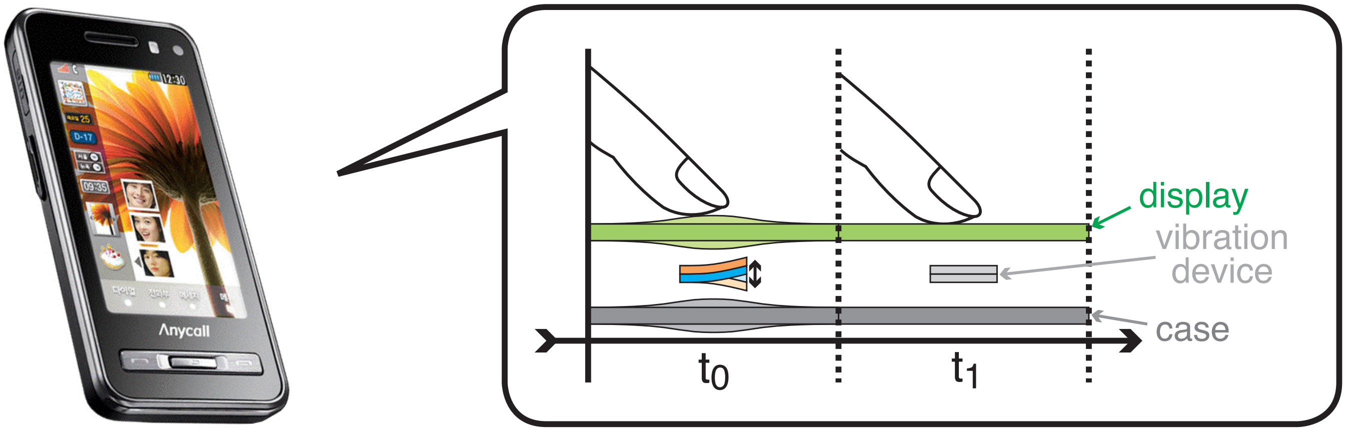

Figure 3. Vibration device: The amplitude of the vibration of the touchscreen can vary according to the position of the fingertip on top of the screen. For example a small amplitude is used if the finger moves above a button (t_0), between buttons no vibrations are felt (t_1). A click on a button is responded by a vibration with a high amplitude[14].

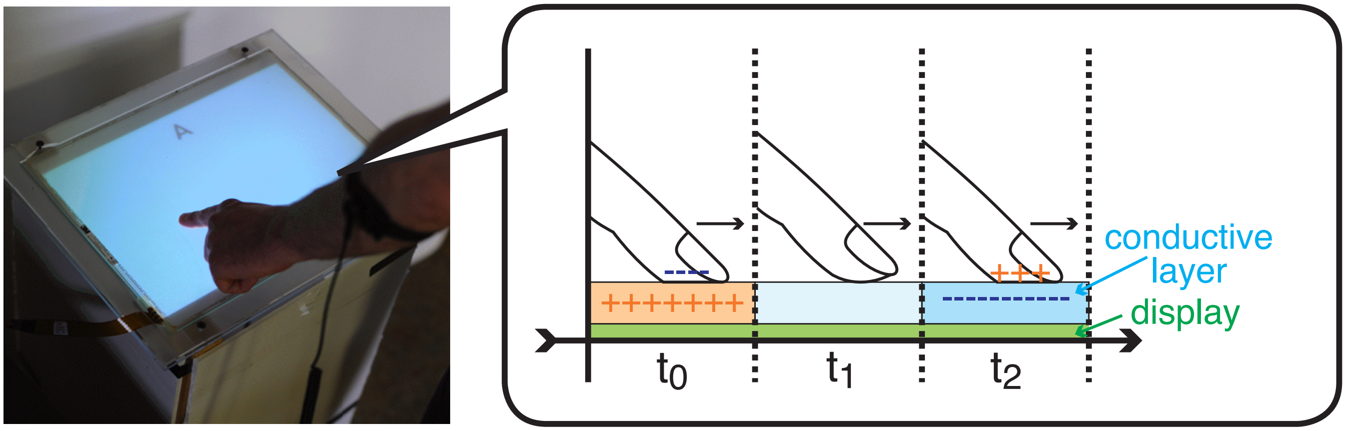

Figure 4. TeslaTouch: A conductive layer above the screen is used to induce an electrostatic charge according to the fingertip position. While no charge results in no additional friction on the above moving fingertip (t_1), either positive (t_0) or negative (t_2) charge adds friction to the moving finger. [16]

quencies and amplitudes can be used to alter the smoothness and stickiness of the surface, which results in a more natural feel of the surface, separating this technology from most other vibration devices.

A conductive, insulated foil is used to create the electrostatic surface charge. While this makes the device easily useable for large screens, without an array of these foils only single touch is possible. Another issue with this technology is the type of feedback that can be given: since friction can only be sensed by movement, no static feedback is possible. This is quite a disadvantage since it denies any feedback on button presses. However, another type of haptic feedback device could be added to fulfill this purpose.

MudPad

While vibration and friction certainly provide a cheap and easy approach to graspable interfaces, the interaction between user and machine is still pretty abstract. Moving a finger over a flat surface and sensing its vibration or friction is still a far way from feeling actual control elements and rather represents a first step in this direction.

MudPad [7] takes a further step into this direction. This technology uses a pouch of ferromagnetic liquid, which changes its behavior in an electromagnetic field as shown in figure 5. As the electromagnetic field changes, it causes the particles in the liquid to build up columns, which decrease the viscosity of the liquid in this spot. While areas without an (vertical) electromagnetic field can be compressed easily, areas with stiffer columns of ferromagnetic particles can actually resist the applied pressure of a fingertip, thereby creating the sensation of touching an object that lies beneath the surface and presses against it. Since the electromagnetic field can easily be changed, the feel of the surface can be altered to give the user a feel of different objects.

The electromagnetic field is produced by an array of electromagnetic coils behind the surface of the screen. For the multi-touch-version of the MudPad, the size of the magnets represents a limitation for the haptic resolution of the screen. While this is definitely an interesting technology, one big

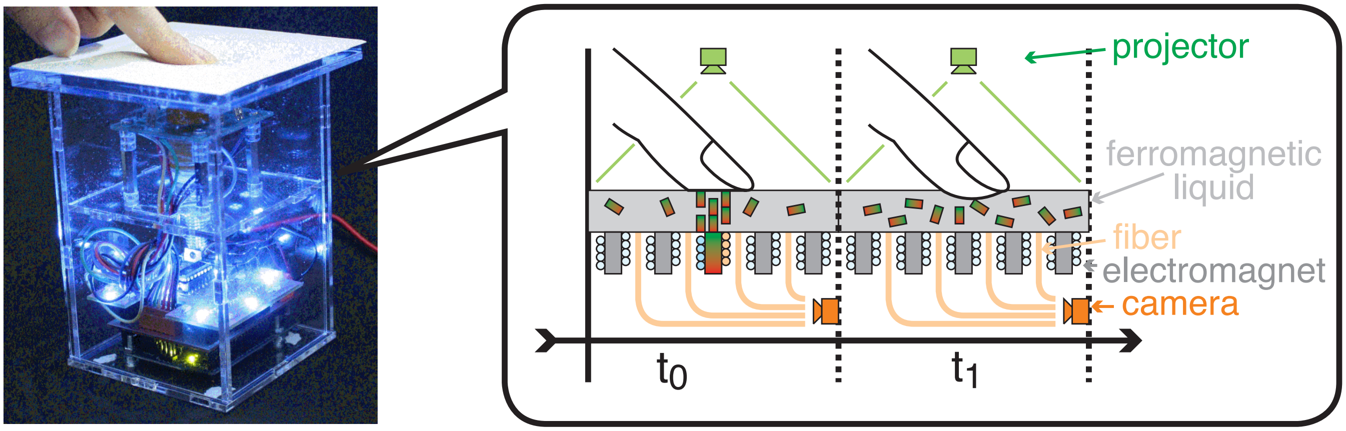

Figure 5. MudPad: The magnetic field produced by electromagnets below the surface of the screen arranges the particles in a ferromagnetic liquid in columns, which stiffens the liquid as shown in t_0 for different polarization of the electromagnet. Without magnetic field the surface could be compressed with the finger and remains relatively soft (t_1) [7].

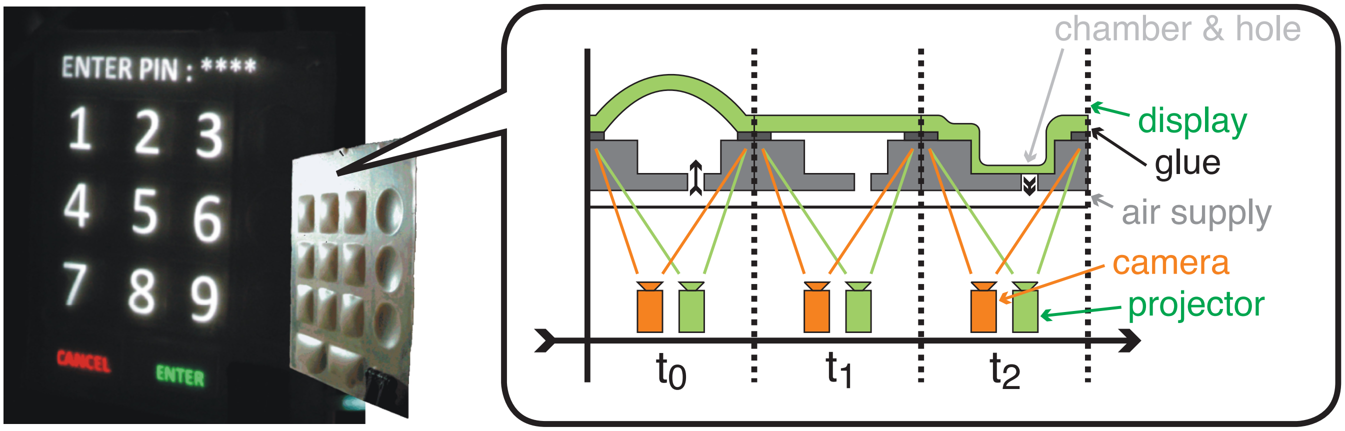

Figure 6. Dynamically Changeable Physical Buttons: A system of chambers connected with a flexible screen can be exposed to high pressure, which results in an expanded surface according to the glued connection between system of chambers and display(t_0). If the air pressure in the chamber is equal to the surrounding pressure, the screen remains flat (t_1). Working with low pressure retracts the display in the hole as seen in (t_2) [10].

issue is that the miniaturization and mass-production of a product using this technology will be very difficult due to the size of the electromagnetic coils needed for the magnet array.

Surface Relief

A theoretically easy way to provide a graspable interface is to add a physically changeable height to every pixel of the output screen. Technological limitations today make this goal seem unreachable, but nevertheless there are interesting approaches for this type of device, which we will discuss in the next section.

Dynamically Changeable Physical Buttons

Scott et al. [10] describe a display, which uses a system of air chambers which are glued behind a flexible display surface as shown in figure 6. The air pressure in these chambers can be heightened or lowered, which results in a change of the flexible surface. The form of the buttons can be changed by either creating high or low pressure in the air chambers. This is achieved by gluing an air chamber of one form over a hole in the surface with a different form. If air is blown into the chamber, the button will take the form of the chamber itself. On the other hand, it will take the form of the hole if air is sucked out of the chamber. Of course this will only work if the air chamber layout is bigger than the hole below it, which is a limitation of the system.

The complex chamber design and the necessary air valves limit the possibility of a really free configurable haptic display with more then these two outputs. If there is a solution to produce such an air valve system in mass production, this would be a very interesting version for haptic feedback in combination with flexible screens.

BubbleWrap

Another kind of chamber design behind a flexible surface is introduced by Bau et al. [3]. The BubbleWrap uses an array of electromagnetic coils sewn to the surface and corresponding permanent magnets in different chambers at the bottom.

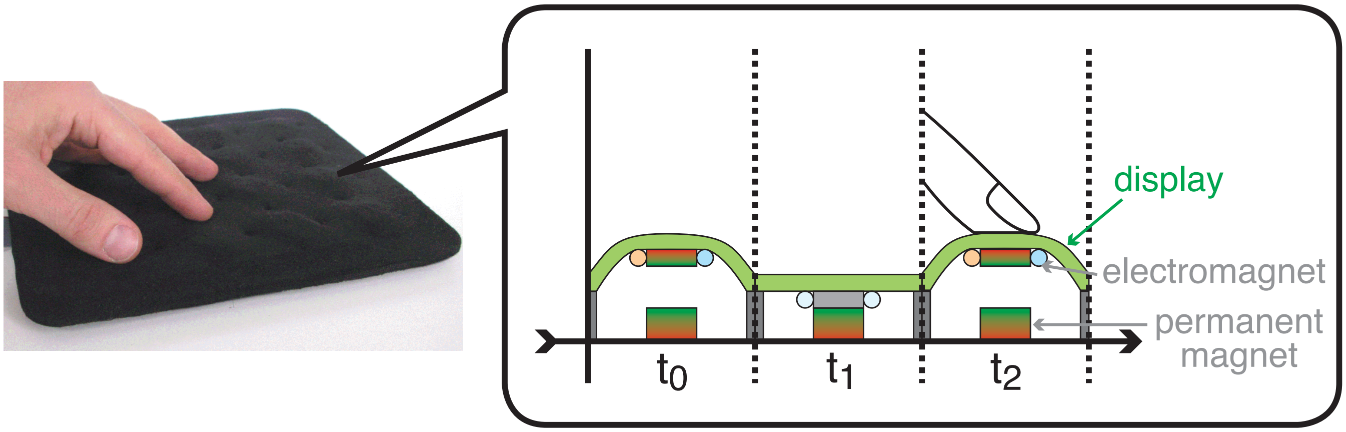

Figure 7. BubbleWrap: Coils sewed to the surface of a textile shell work as electromagnets over permanent magnets at the bottom of the shell. Without current in any coil no electromagnetic field exists in the according cell of the shell and it remains flat (t_1). With an electromagnetic field the cell is expanded (t_0) and remains firm even under pressure of the fingertip as shown in t_2 [3].

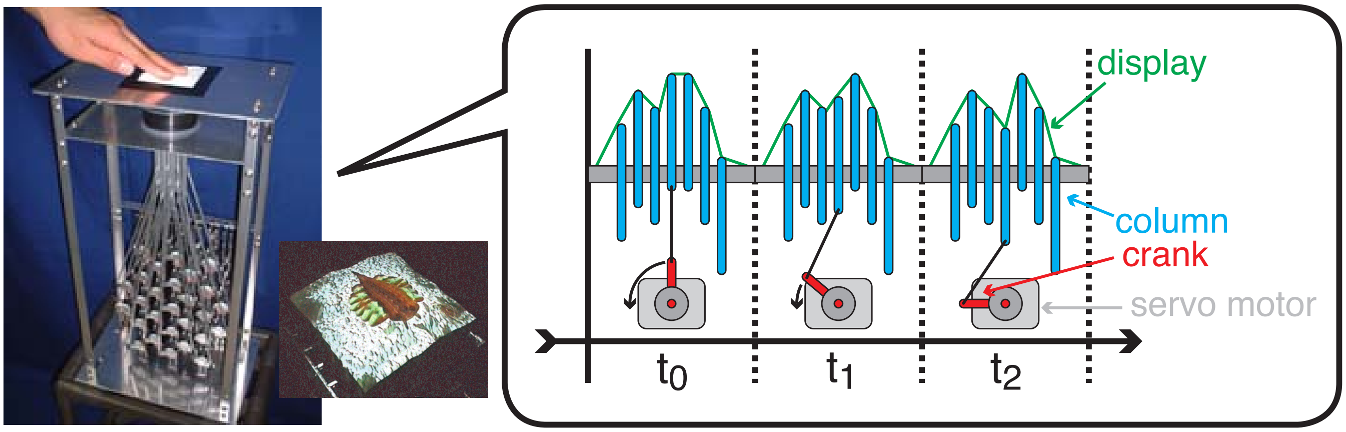

Figure 8. FEELEX: An array of columns under a flexible surface can be lowered or heighten by lifting engines under each column to change the surface relief over the time (t_0 to t_2). [9]

The electromagnetic field is used to expel the magnets and therefore heighten the according surface to create a surface relief. The height of the cell is proportional to the current flowing through the according coil, while the electromagnetic force gives the heightened cell a firm feel. Apart from this change of firmness and shape, vibration feedback is additionally possible (figure 7).

A similar device is the Super Cilia Skin [13], where instead of the flexible skin itself a array of rods with attached magnets on a flexible skin is used to produce a kind of grass field. However, these structure make the system much more costly in comparison to BubbleWrap.

Both devices could be used on tabletop systems such as the Actuated Workbench, which we will describe later.

Feelex

Finally, the display can be made of separately movable, enlightened columns. For a smoother surface, these columns can be hidden behind a flexible skin as described by Twata et al. [9]. Through vertical movement of these columns the surface relief can be modified by the computer and by responding on user input also by the human.

The movement of the columns can be achieved by electrical rotational motors and a piston-crank system to improve the resolution (figure 8) - in this case the device is correspondingly bigger than the screen. Other versions use linear or piezoelectric motors to raise the columns. Another possible variant might use air cushions or electromagnetic fields similar to the above mentioned Dynamically Changeable Physical Buttons [10] and BubbleWrap [3].

While a resolution of 8 mm columns is enough for a good haptic feedback, it is not sufficient if used for optical output like a normal screen. With a flexible screen and/or a surface projection system these limitation could be annulled, but the third dimension resolution remains insufficient. This is a problem shared by all the devices in this section which will probably not be solvable in the near future, as it seems very hard to miniaturize any of the described technologies to a degree that would be sufficient for high-resolution displays.

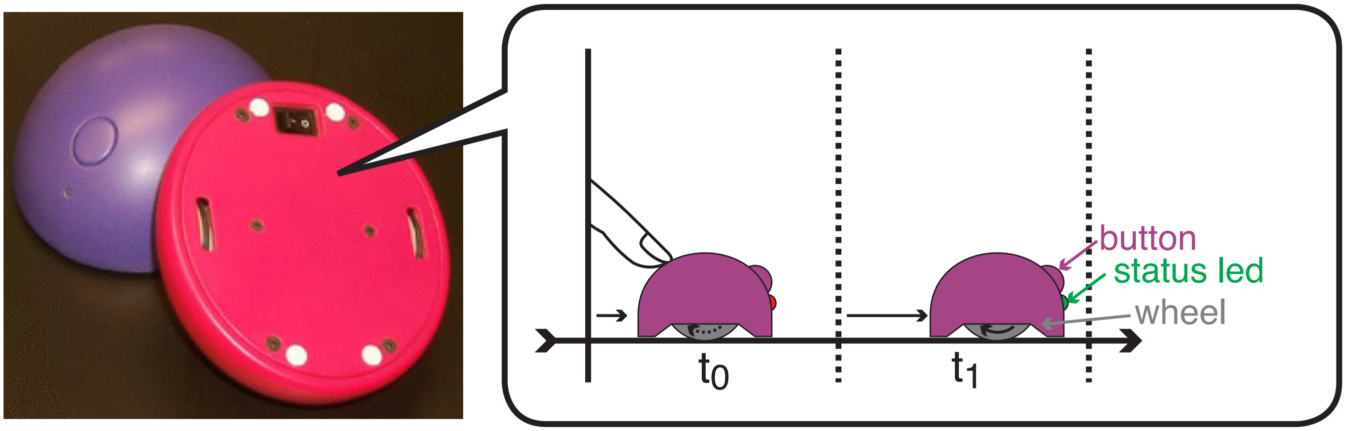

Figure 9. curlybot: A palm-sized robot can moved by the user (t_0). These movements are sensed and recorded by the wheels. In a second state the curlybot moves according to the recordings (t_2). Pressing the button toggles between these two states, indicated by the led. [4]

Object movement

In the next section, we will focus on another type of actuated devices which actually use movement of physical objects to give direct feedback to the user.

Curlybot

One type of actuated devices are devices that can move on their own, like curlybot [4]. Equipped with an own engine and steering mechanism, this device can be used to record and replay movements (figure 9).

The engine and steering consists of two electrically driven wheels, which are also used as sensing device for motion recording. One button on top of the curlybot switches between recording and playback. With the right kinds of recordings, complex shapes and patterns can be created easily.

This device is used for educational purposes and aims to teach young children a basic understanding of mathematics and geometry. Other robotic devices are modular and can be used as a constructive assembly system to represent complex digital objects and their behavior. These devices could also be used as an output and input device if they could have a remote connection to the computer.

Pout

The Pout, developed by Ng et al. [17] offers another interesting example for this type of technology. Imagine a pin-board the user can pin documents to. As he does this, a video camera, which is focused on the board, creates a digital image of the document. This would make a perfect example for a tangible user interface: Instead of creating a digital document by typing it into the computer, it is pinned to a different kind of interface, triggering the creation of a document by the computer. We have commented on the possible inconsistencies of tangible user interfaces before: It would probably not be a big problem to make the computer delete the digital document automatically if the user removes the physical document from the board. But what happens if the digital document is deleted? The Pout offers the solution: When the digital representation of the document is deleted, the pin-board can just eject the physical document, thereby letting it fall down to the floor. This is achieved by creating special pins, the so-called pouts, that can eject themselves from the pin-board when given an according signal.

The pin-board is made up of three layers of conductive sheet, which are used as wires for power, data and ground. The pouts consist of connectors, which height differentiates in order to reach the different layers when the pout is attached. If a digital document is deleted, the computer sends a signal through the data layer to the corresponding pout, which then withdraws the connector pins via muscle wire in the housing. This causes the pout to fall down and release the document, as shown in figure 10. After a document is released, the pout can be put back into its initial state with the press of a button, which extends the connectors back from the housing.

This technology allows for a very clear structure of the working process with both digital and physical documents and could even be used to synchronize several working spaces. For now, this only works with one pin-board and several digital workstations.

Of course, for synchronized pin-boards to work, there is still one missing link: If a document is removed from the pin-board, it could be removed on all the pin-boards. But an added physical document can not just be added to other pin-boards. However, this could be solved using a projector that shows the image of the added document on all other pin-boards, thereby extending this idea even further.

The Actuated Workbench

We have discussed the difficulties of tangible user interfaces in the multi-touch tabletop environment before: For example the SLAP-Widgets we have introduced earlier could not be rearranged by the computer to change the user interface similar to changes of the graphical user interface. With the Actuated Workbench [18], Pangaro et al. introduced a possible solution to this problem: They added an array of elec-

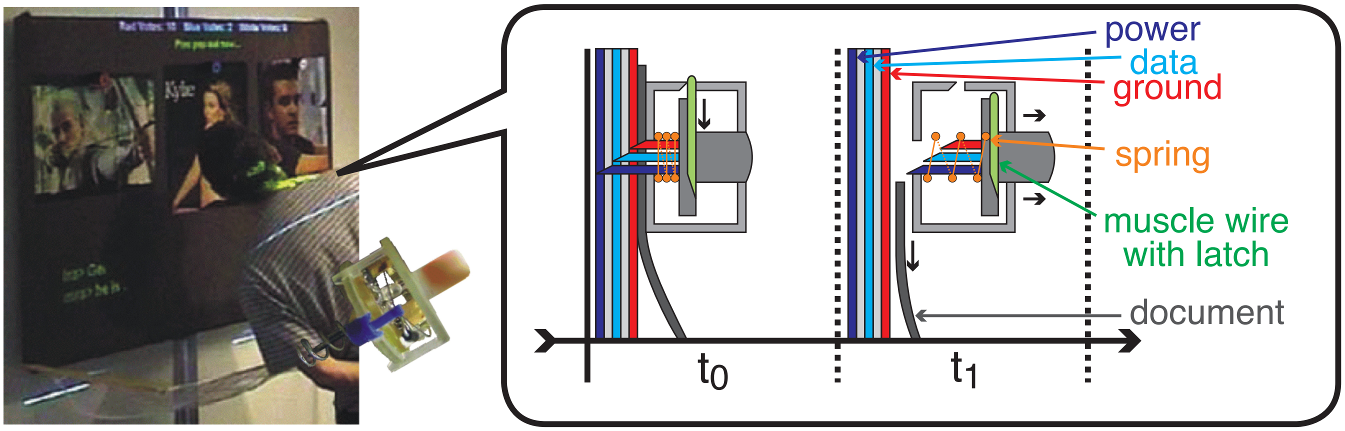

Figure 10. Pout: The pin of a pin-board consisting of three conductive sheets for electric and data connections with according connectors can be released by retracting a latch by a muscle wire (t_0). This results in a retraction of the connectors in the housing by a spring and the release of the pin from the board (t_1). The user can reattach the pin by pressing on top of it, causing the connectors to emerge from the housing again. [17]

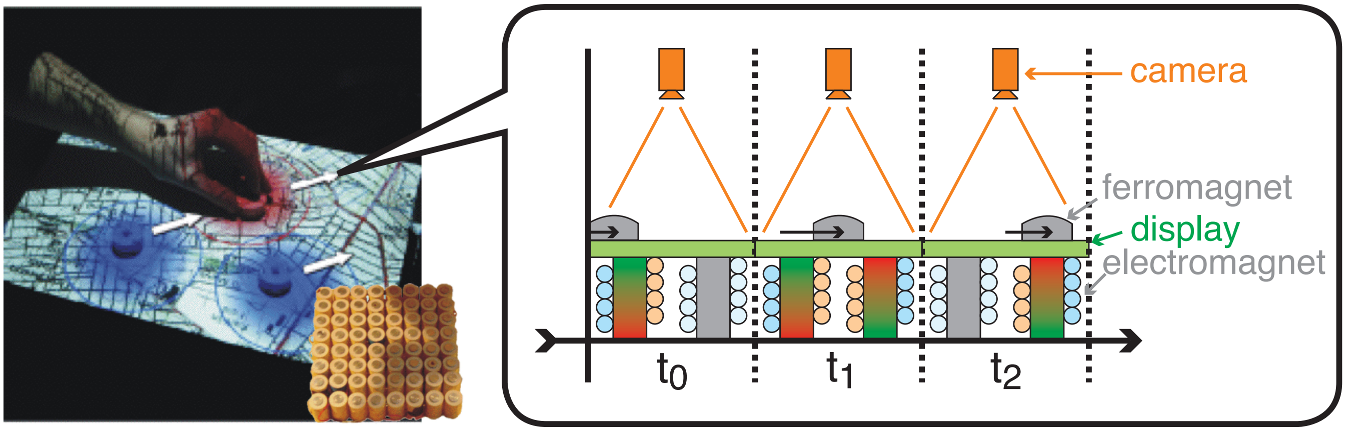

Figure 11. Actuated Workbench: ferromagnetic material can be moved on the surface of a screen by an underlying array of electromagnets. Since part of the electromagnets are remaining passive through the distance to the moved object like in t_0, other objects can be moved at the same time. These objects can also be rearranged by the user as shown in t_2 [18].

tromagnetic coils below the surface of the multi-touch tabletop.These electromagnets can be used to move pucks containing permanent neodymium magnets over the table (figure 10).

This creates the possibility for the computer to make up for possible inconsistencies by simply repositioning the physical objects, in this case the pucks, instead of relying on the user to do so. But this technology has further implications: Since the computer now has a way to directly influence the physical objects on the table, many sorts of different possibilities that are already known in the digital realm are now possible on the tabletop environment. Since the system keeps track of the positions of the objects on the table, an undo function is possible.

The authors also describe a possible search functionality: When many pucks are used on the tabletop, the user might become confused and have trouble finding a specific object that represents the digital item he wants to interact with. The computer could now find this item for the user and show it to the user by wiggling it around or simply move it to another location on the table. Another option is the introduction of physical restraints to the user. The computer could hold certain pucks at one position or not allow them to move into a certain area of the table and thereby translate restrictions that apply to the digital object into the real world.

Madgets

Madgets are the consequent next iteration of the SLAP-Widgets we have discussed earlier. Many functions of the madgets are very similar to what we already described for the SLAP-Widgets, so we will now focus on the new developments which differentiate madgets from the SLAP-Widgets.

Inspired by the Actuated Workbench this project adds an array of electromagnetic coils below the surface of the multitouch tabletop. But this project takes the idea a step further: Not only can the Widgets themselves be moved over the table, knobs or switches can also be set to different values in order to depict the change of values on the digital side. This is accomplished by adding several different magnetic mark-

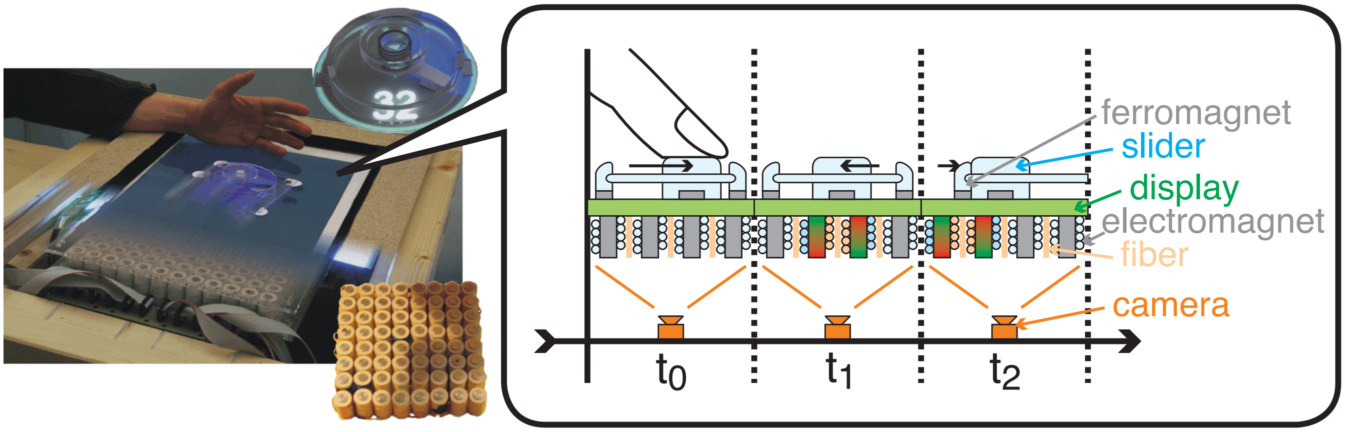

Figure 12. Madgets: Using both SLAP and Actuated Workbench technology, the position of translucent objects equipped with ferromagnets can be detected by an infrared camera. They can be used just like SLAP-widgets by the user (t_0), but also by the computer via ferromagnets on the movable parts (t_1). Additionally, the whole object can be moved by the computer, too (t_2) [1].

ers: Some of them are used to move the madget, others are attached to moveable parts of the madget. If controlled correctly, the electromagnetic coils can hold the madget in one place while rearranging the adjustable parts. This principle is shown in figure 12 for a slider as an example.

This solves the problem of inconsistencies between the physical and digital world and also enables the developers to create widgets that would otherwise not have been possible: A bell madget, which uses an actual bell, rung by a magnetic moveable piece of metal. This madget can be used to generate alarm sounds to get the users attention. It is even possible to control the frequency of the sound. Also, with the help of induction, a LED-Madget can be powered through the electromagnets below without the need for any cables [1].

However, the introduction of the described array of magnets also introduces an important problem: The coils need to be positioned closely below the surface and therefore block the vision of any camera below the table. While the Actuated Workbench solved this problem by simply putting the camera above the table, this project offers a different solution: To still be able to sense the madgets position, fiber optic cables are positioned in between the coils. These cables transmit the infrared light to the camera below the magnets.

CONCLUSION

We have described many different types of technologies that use actuation. As we have seen, there are basically two main themes in the current development: On one side, there are many efforts to create interfaces that add a haptic dimension on top of graphical user interfaces. This improves the user experience in different ways: While most people are used to get a tactile feedback on their actions in the everyday life, most interaction with a computer was lacking this feedback, so it is generally a good thing to introduce this kind of feedback to the interaction. Furthermore, tactile feedback allows systems that still are mainly based on a graphical user interface to be operated blindly in certain situations. On the other side, there are concepts for tabletop systems that not only add tactile feedback but physical objects in order to improve the user experience.

However, most of the projects we have introduced are basically proof of concepts. Now we want to have a look at different ideas that show how these concepts can actually be efficiently used.

One very interesting project by Patten and Ishii [6] called PICO employes several technologies we have presented thus far: It uses moveable pucks on a tabletop surface, just like we have seen the Actuated Workbench use, to create a way for user and computer to collaborate on tasks that would be actually quite hard for either side. Consider the following example which is introduced by the researchers: Planning the placement of cellular telephone towers is very hard for several reasons. One of the most important goals will be to get the best possible reception at every point of the area that needs to be covered. In an ideal, simplified world, the Computer, given an exact model of the terrain, would be able to calculate a model which would allow for the very best overall reception. But there are many constraints to be considered, which can lead to problems when deciding on the best solution. There might be different opposing goals that might not be easily quantifiable, therefore leaving many different possible combinations of locations as valid solutions. The user himself might have a better concept of some of those ambivalent constraints than the computer but will not be able to be aware of all the computational constraints. By collaborating with the computer, the user can overcome this problem and use his knowledge as efficiently as possible. The researchers implemented a system that allows the user to place physical objects that represent the cellular telephone towers on a tabletop like the Actuated Workbench. Now the user can move the towers while the computer senses their position, calculates the coverage that would be possible from this position and display the resulting coverage on the map. With Actuation, the computer can also make the user feel a resistance when he moves a tower into a part of the map where a worse coverage of the target area would be achieved.

Another interesting topic might be the collaboration on multi-touch tabletop-systems such as the Actuated Workbench or PICO over a long distance. If two or more tabletops are setup in different locations, they can easily be synchronized using the technology discussed in this paper. Objects that are moved by a person on one of the tables could be moved by the computer on the other table. Enabling this kind of interaction could definitely enhance remote conferences, creating yet another interesting implication for this Technology.

Overall, it seems like even the actuation-technology that already exists today is not being completely put to use yet: There probably are still many applications for this type of interaction to be discovered and the ones that are discovered are mainly used in a scientific context. One major issue that will need to be solved for actuation to really become a viable technology in everyday life is the miniaturization of rather complex devices.

For example, the vibration and maybe in near future the TeslaTouch system for the haptic touchscreen feedback could improve user input for smart-phones. Piezoelectric linear drives might be used for systems like the Feelex. With electromagnets in its columns maybe even Madgets could be combined with a changeable surface. Another possibility is the use of piezoelectric valves or a direct oxygen pumping system for volume changes of a chamber system for the surface modifications.

As we have seen, many of the presented projects relied on large mechanisms that were hidden from the user, but make any usage in a mobile context seem impossible. This is especially important because many of the effects of haptic feedback, apart from the tabletop environment, could vastly improve blind interactions, which would be especially important for the usage of small, mobile devices rather than stationary devices.

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