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Published in:
Personal and Ubiquitous Computing

DOI:
10.1007/s00779-006-0137-9

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

Easy Doesn't Do It: Skill and Expression in Tangible Aesthetics

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In this paper, we articulate the role of movement within a perceptual-motor view of tangible interaction. We argue that the history of human-product interaction design has exhibited an increasing neglect of the intrinsic importance of movement. On one hand, human-product interaction design has shown little appreciation in practice of the centrality of our bodily engagement in the world. This has resulted in technologies that continue to place demands on our cognitive abilities, and deny us the opportunity of building bodily skill. On the other hand, the potential for movement in products to be a meaningful component of our interaction with them has also been ignored. Both of these directions (design for bodily engagement and the expressiveness of product movements) are sketched out, paying particular respect for their potential to impact both interaction aesthetics and usability. We illustrate a number of these ideas with examples.

Movement, tangible interaction, aesthetics, motor skill, expression, robotics

Introduction

In interacting successfully with our physical world, our bodily movements and the perception of movement in our environment are essential. Yet movement plays a more than merely functional role. Both our bodily movements and the perception of physical movement may contribute to the aesthetic of our experiences with interactive products. Performing bodily movements and building bodily skill can be both challenging and highly rewarding, whilst we are also perceptually sensitive to the beauty and expressiveness of movement in our physical environment. In this paper we discuss the relevance of movement to the design of intelligent products.

This work is part of our perceptual-motor centred approach to tangible interaction, which capitalizes on the fit between physical objects and our motor abilities as well as on our sensory sensitivity to the rich expressiveness of physical objects, and develops interaction styles which value movement of the body as well as movement of product components. Through such movement-focused interaction styles, we aim to offer not only improved usability but also aesthetically rewarding experiences. Drawing on a variety of disciplines, including philosophy, perception psychology, anthropology of skill, kinetic art and human-computer interaction (HCI), we expand on how the relationship between movement, aesthetics of interaction and tangible interaction may impact the design of intelligent products.

We start with a discussion of the emerging views of aesthetics of interaction. We discuss why it is topical, how we see its relationship with usability, and what approaches are mentioned in the literature. Our interest is in how the physical movement of both person and product, as well as the coupling between them, impact interaction aesthetics.

Following this, we describe the recent ‘turn’ to embodiment in systems design, explaining how it reconceptualises the role and importance of the body. Embodiment argues for a re-appreciation of the body, and that meaning in interaction is best understood as being created during bodily interaction, rather than as the perfunctory implementation of pre-planned schemata.

Whilst the idea of embodiment has influenced HCI theory for the last twenty years, it appears to have realised little of its potential to impact interaction design for products. An overview of the historical development of commercial products in the 20th century shows how products have increasingly neglected our perceptual-motor skills, have burdened our cognitive abilities, and have lost their physical expressivity. This opens up two movement related lines of inquiry. First, we argue that new interaction styles should exploit the user's refined dexterity and potential for skilled action. Second, we look to design products that are able to move in expressive ways.

Our discussion highlights six issues that a consideration of movement for interaction design brings into focus. These relate to how we should conceive of interaction, aesthetics, graphical user interfaces, tangible interaction, anthropomorphism and the coupling of movement-based input and output.

In the final part, we argue that physical user actions and product reactions should not be seen as separate. The coupling between action and reaction is quintessential to interaction and considering the coupling of physical actions and reactions opens up a new space for design aesthetics and movement-based interaction.

An essential aspect of this article is movement. Since movement is difficult to capture in photographs, we also provide movies at http://homepage.mac.com/j.p.djajadiningrat/movement.htm. The text points out when movies of a design concept are available.

Aesthetics in interaction design

A changing view

With the convergence of consumer products, telecommunications and computing, 'computers' are no longer restricted to the workplace but play an increasingly important role in our homes and leisure time in the form of all kinds of microprocessor controlled products, be it washing machines, phones, cameras or audio-visual equipment. Therefore an efficiency-focused approach to interaction may no longer suffice: it needs to be complemented by knowledge on the aesthetic aspects of the user experience. This requires a more holistic view on interaction in which beauty and enjoyment are taken into account too [1][2][3][4][5]. Many intelligent products look attractive at first sight, but turn out to be ugly in use. Can intelligent products be designed in such a way that they are not just beautiful in appearance, but also beautiful in use? This question has led to a new research field called 'aesthetics of interaction'.

The relationship between usability and aesthetics

It is a widely held view that since poor usability negatively influences the beauty of interaction, any usability issues need to be solved before adding the complexity of aesthetic considerations. Whilst it is clear that frustrating interaction allows no aesthetic experience, there are other, less obvious mechanisms through which aesthetics positively influences usability. For example, users may engage and persist in interaction because products tempt them, raise curiosity or are intriguing. Norman even claims that "attractive things work better" [6]. If aesthetics improve the perceived usability of a product, this leads to the question: what kinds of aesthetic sources do interaction designers have at their disposal?

Different types of interaction aesthetics

In industrial design, the focus is often on the aesthetics of appearance of behaviourally passive objects [7][8]. This understanding of aesthetics falls short for interactive products, since the essence of interaction is that products react and exhibit behaviour. Aesthetics of interaction, then, is about the quality of experience in interactively engaging with a product.

Recent papers illustrate different directions. There is an *aesthetics of narrative* in which products, through their appearance and interaction, become carriers of ambiguous stories which instil aesthetic reflection [9]. Buur et al. focused on an *aesthetics of actions* which centres around the expression and contextual fit of the user's physical movements [10]. On the output side, Maeda [11] researched *reactive graphics and computational aesthetics* resulting in 2D output on a screen or print, whilst Kyffin et al. [12] investigated the *semantics of movement* of products that react through physically moving parts.

Clearly, when we treat movement as fundamental to interaction design, we need to reconceive our understanding of 'aesthetics'. However, there is a yet more radical reconception of human nature that is essential to a discussion of movement in interaction design, which is the philosophy of 'embodiment' which places the body at the foundation of our existence in the world.

Rediscovery of the body

The philosophical notion of 'embodiment' has slowly, over the past twenty years, grown in influence with respect to the design of interactive systems. Embodiment is a central plank in Winograd and Flores' Heideggerian critique of cognitivist understandings of the use of computer systems [13]; it is, in a different sense, also a vital theme in Suchman's ethnomethodology [14]. Furthermore, embodiment has been fundamental to ideas that have developed out of Deweyan pragmatism (e.g. [15][16][5]), Gibson's ecological psychology [17] and other strands of phenomenology (e.g. [18]). In different ways, each of these approaches has been advanced as a corrective to the Cartesian mind-body split. Whilst not entirely compatible, they share a realisation that the body is not merely a tool for our use in accomplishing our purposes, but itself constitutes our very possibility for interaction in and knowledge of the world. In different ways, this family of responses to cognitivist conceptions of mind highlights the fundamental dependence of any and all human understanding on our ordinary, pre-conceptual, bodily, lived experience of the world. In an important sense, then, the tables are turned on cognitivism; the mind is not seen as the entity from which springs all human action, language, culture etc. Instead, our 'mindful' capacities are dependent on our socially shared forms of life and our bodily possibilities for engaging with the world.

Anthropological work has proven one important appropriation of these ideas, particularly with respect to rehabilitating the notion of bodily skill as an embodied phenomenon. For example, Ingold's [19] refusal to abstract "the components of intelligence, sensibility and expression that are essential to the accomplishment of any craft from the actual bodily movement of the practitioner" echoes the centrality of movement, rather than movement *schema* or *instructions*, to skilled practice. Dreyfus and Dreyfus [20] point out that many of the most commonplace activities, such as tying shoelaces, resist codification in the form of generative rules or algorithms. Empirical support for this view is provided by Ingold [19] who describes an experiment in which subjects carried out a complex knotting action guided by an illustrated manual. They experienced that it was very hard to convert the verbal and graphic descriptions into actual bodily movements. In fact, whilst the instructions were intended to tell one how to move, it was not possible to understand them until the movement had been accomplished. This experiment, then, makes a case for embodied knowledge in which meaning is created during actual, physical interaction rather than being abstractable beforehand in schemata.

However, the design implications for such foundational reconceptualisations are still in the throes of being worked out. Robertson [21] and Dourish [22] are rare and sustained attempts to do this (although bodily skill is notably not a focus of Dourish's treatment of embodiment). Although none of these 'embodied' philosophies are particularly recent, embodiment has not been the view that has historically dominated the practice of interaction design.

For example, in the prevailing view on interaction, ease of use requires the user's actions to be as simple as possible. The drawback of such an approach is that it shifts the complexity from the motor actions to the decision process of what to do. It is exactly because button pushing is so simple from a motor point of view that learning is shifted almost completely to the cognitive domain. This approach to interaction is likely the result of the implicit adoption of a 'disembodied' view of intelligence and action, in which mind and body are fundamentally distinct; where the superior mind is the agency which puts the inferior body to work [23]. This rather deprecating view of our physical engagement with the world is critiqued by Ingold [19] as it reduces making and doing to "...the mechanical application of a set of operational principles—something akin to an instruction manual—which the practitioner is bound to put into effect, regardless of context or previous experience". Current interfaces indeed seem to be built on the assumption that interaction can be captured in schemata and that the body is merely a mechanical executor. This view, however, does not do justice to our embodiment in the world.

A perceptual-motor view of tangible interaction

One emerging interaction movement which holds promise to remedy the aforementioned disembodied view of intelligence is tangible interaction. Opinions on its definition still differ. However, one approach within it that we have contributed to developing—and one that is particularly relevant to the design of intelligent products—is how interaction with physical objects can exploit mankind's sophisticated perceptual-motor skills, i.e. on how people perceive their environment and what they can do with their body [24][25]. To explain the relevance of perceptual-motor skills to intelligent products, a historical overview is given of how human-product interaction has developed over the twentieth century. It is our particular concern to chart the increasing neglect of the body with respect to human-product interaction, using this as a basis to propose design responses, building from our understandings of interaction aesthetics, embodiment and tangible interaction, as correctives to this trend.

The historical neglect of the body in interaction

Learning from history: tangibility in the 20th century

Many products—for example cameras, radios and phones—share a common historical pattern of development. Some aspects of this pattern are clear: functions proliferate, products become smaller and more mobile, and electronics and computing are added. Other aspects are perhaps less obvious: interaction becomes less physical and form and configuration become less expressive. Øritslund and Buur [26] identify a number of so-called interaction styles in 20th century history, three of which are discussed here to illustrate a trend. Obviously, transitions between styles are not clear cut and vary between different products.

Machine cowboy

During this era, lasting until approximately the second world war, products are mechanical or electro-mechanical, resulting in heavy actions and rich feedback. Although there are few controls, the actions required are quite diverse.

There is a direct link between form, action and function. The form of the product is dictated by the mechanisms and the overall form changes as these mechanisms move or are moved from one position to another. The user's actions act directly on these mechanisms. Products express their functionality in their forms and required actions, allowing users to directly and physically access functionality.

Analogue professional

In the fifties, user actions become less heavy as electrically powered components replace purely mechanical switches and mechanisms. The controls no longer demand movement of the whole arm or even body. Instead, movement of the hand suffices. The number of controls—many of them analogue rotary controls and sliders—increases. Losses in the tactile feedback from the mechanisms begin to be compensated by visual feedback in the form of precision dials and scales.

Design increasingly becomes driven by ergonomics and aesthetics, hiding the encased technology and therewith any meaningful functional components. Housings grow more similar and the visible movement of product components becomes limited to the control panels. The increasingly standardised controls become less differentiated and expressive in both their appearance and the required actions.

Digital hacker

With the rise of the micro-controller in the eighties, push buttons are favoured over analogue controls. The number of controls drops off as the one-function-per-control approach is replaced by a many-functions-per-control approach. Products become like miniature computers with keypads and screens, often inheriting the graphical user interface style, complete with icons and pointing devices.

The repertoire of actions has become very narrow: the only action required is pushing. Movements have become very precise and take place at a finger level rather than a hand, arm or body level. Feedback is nearly all visual and provided by displays. The form of the product and the controls do not change: 'form' changes are limited to changes on a display. There is no longer any perceptually meaningful link between actions, form and feedback. Regardless of function, products feature the same 'display+push button' interfaces. These rely mainly on the users' cognitive skills, stretching their abilities to learn and remember.

Reflection

Product design history thus shows an increasing emphasis on cognition and a loss of appreciation for perceptual-motor skills. It is the decreasing expressiveness of appearance, the loss of motor skills and the increasing opacity of the action-form-function relationship, that are relevant to our perceptual-motor view of tangible interaction. Very different functions are triggered by the same actions which result in similar looking output. With little differentiation in appearance and actions, there are no 'hooks' for the perceptual-motor system to get a grip on a product's interface. Yet differentiation by itself would not suffice: the ultimate goal is the meaningful coupling of action, form and function. Differentiation in actions and appearance is not just a usability issue, it may also contribute to a rich, aesthetic experience. The trends we have charted here reveal a number of shortcomings in the development of 20th century human-product interaction design with respect to both interaction aesthetics and embodiment.

Although the notion of bodily interaction with technology has been explored within other (predominantly software) design arenas such as computer-supported cooperative work (CSCW), augmented and virtual reality (AR/VR), and gestural interfaces, many of the resulting concepts do not easily map to human-product interaction. Intelligent products often pose practical requirements which are peripheral to the concerns of these communities; for example products often need to be, amongst others, monolithic, non-immersive, portable and non-encumbering.

In some of these cases, there are also more fundamental differences. While many would argue that AR/VR systems are an epitome of embodied technology, they 'embody' a very different understanding of embodiment than the one that we favour. For one, AR/VR systems rarely address the notions of motor skill and manual dexterity. In fact, most AR/VR systems work with simple collision detection and ‘grabbing’: they do not aim to transfer our real-world skills into the virtual environment. More importantly, however, AR/VR environments which generate shared 3D virtual spaces, objects and actors re-present a re-constructed world that, no matter how intricately detailed, shares only selective and superficial similarity to the world in which we have embodied familiarity. In this sense, they cannot seamlessly enable us to transfer our understanding of the world and its various meanings to our interaction with the system.

Many gesture-based systems also struggle with the meaningful coupling between form, action and function in which the appearance of the product cues the user on the ‘vocabulary’ of actions that can be recognized [27]. As Cassell puts it: “I don't believe that everyday human users have any more experience with, or natural affinity for, a "gestural language" than they have with DOS commands.” [28]. Whilst many gesture-based systems rely on non-contactual actions (gestures in space) or actions on a form-wise non-defined surface, we see the challenge in human-product interaction to be the linking between the physicality of the object and skilled actions, Part of the embodiment challenge, then, is to create a physical, contactual and dynamic fit between human and product.

In the following, three of these interaction deficiencies are expounded on and for each an alternative view based on rich, bodily motor actions is proposed.

Design opportunities for bodily interaction

From de-burdening cognition to exploiting physical memory

Improvements in usability are commonly focused on preventing cognitive overload, for example by reducing the necessity for 'knowledge in the head' by substituting it for 'knowledge in the world' [29]. However, interaction design rarely addresses our physical abilities; in fact, the required motor actions are trivial from a physical point of view.

Instead of aiming for products which do not require physical learning, interaction design could include consideration of the physical learning curve. Such a learning curve needs to allow operation by novices as well as the development of bodily skill. Here we propose two approaches to input which focus on the acquisition of physical skill and how physical procedures can become engrained with time.

Movement flow

A new approach may consider a movement flow through a complete sequence of operations. Designing for movement flow would require simultaneous consideration of body postures and the positioning of the controls, from both a spatial and a temporal point of view. Jensen et al. describe a study of a brewery technician carrying out checks of a conveyor belt system [30]. Even though the system was not designed with user movements in mind, its physical, spatial nature allows the technician to optimise the fit of his bodily movements and timing to the system.

A comparison may be drawn with fingering in playing a musical instrument, in which the use of fingers and hands is fitted to the player’s physical abilities as well as the characteristics of the instrument. Fingering allows movement to become engrained with repeated practice without hiccups in the flow obstructing this process [31].

If interaction were similarly carefully choreographed, with repetition the user may be able to flow through actions with increasing motor confidence. More than time saving or ergonomic comfort, this may also be about the expression or beauty of the movement [32][33].

Movement contributing to effectivity of function

In interaction design, only the movement to operate the controls is considered functional, with the movements in between forming time consuming necessities. A different approach may let the movement between the hotspots contribute to the functionality. This changes the movements in between from 'non-functional, but necessary' to contributors to function.

A comparison could be drawn with martial arts. During training one does not learn to punch or kick harder through concentrating on the hotspot actions. Instead, emphasis is on practising the movement in between the hotspots: circular movements, directional harmony between torso and limbs, 'untensioning' etc. In martial arts this approach works: one practises the movement to find out that the resulting 'hotspot action' is indeed more effective.

A similar approach in intelligent products may encourage users to build skill as their movements would then influence the functional end result. A consequence is that interaction will have to let go of the idea of functionality being of fixed quality. Instead, the quality of the outcome would differ with the user's actions.

From frustration of motor skills to challenge and pride

In a critique of computer interfaces, Buxton tells a story of how in a far future, aliens try to reconstruct the extinct human race based on an archeological finding of a 1990s computer [34]. Amongst the conclusions are that humans had one hand with many fingers and another with one non-touch sensitive finger. Were this extended to digital hacker style products, the conclusions would be even more extreme: humans would seem to have had only one, non-touch sensitive finger. Clearly, the relevance of this anecdote is that mankind's refined dexterity is completely wasted on the action possibilities of computer interfaces as well as intelligent products: the interaction in fact frustrates people’s physical abilities.

The opposite of the frustration of motor skills is the challenge and pride that comes with acquiring and possessing motor skills. Research on what makes (computer) games enjoyable suggests that challenge is an important contributing element [35]. The difficulty of the game task should be a little more demanding than the user's current skill level so that the user is required to put in extra effort. At the same time, the attainment of the goals should be feasible in the eyes of the user, yet not too easy in order to remain challenging. Then the accomplishment of a goal results in a feeling of pride. However, it is not so much goal attainment itself, but the activity leading up to it that affords enjoyment and pride[36]. Interestingly, this suggests 'ease of use' may just as often lead to frustrating experiences as it does to 'good usability'.

From narrow bandwidth to simultaneous analogue control of multiple parameters

The information that can be communicated through a button is highly limited: on or off. This minimal communication is a far cry away from the internal complexity of many intelligent products, which call for the adjustments of dozens of parameters. Since the actions in themselves are simple, many need to be strung together to build meaningful communication, resulting in long sequences (Figure 1). In engineering terms, the input bandwidth of buttons is very narrow, establishing a bottleneck between human motor skills and the product's parameters.

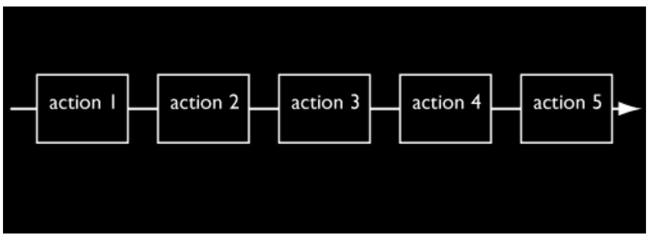


Figure 1: The narrow input bandwidth of buttons leads to long sequences of simple actions

There are two ways to increase the input bandwidth of intelligent products. The first is to move from binary to analogue controls. We would like to emphasize here that we are not proposing to ditch digital in favour of to analogue technology 'under the hood'. Instead, we propose to consider analogue type controls on the user-interface level to interact with digital technology. The second is to move from controlling a single parameter at a time to controlling multiple parameters simultaneously. By making the building blocks of interaction more complex, allowing changes to be made in parallel rather than only sequentially, the number of actions can be decreased yet the level of control dramatically increased (Figure 2).

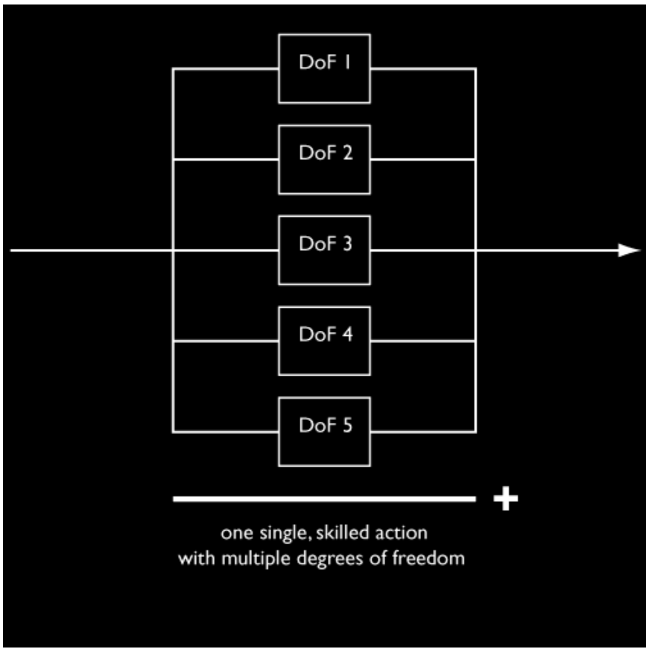


Figure 2: By exploiting the body's multiple degrees of freedom (DoF), a number of parameters can be controlled in parallel through a single, skilled action

The many degrees of freedom of the hand allow for control of multiple parameters at the same time. Combinations of twisting, rotating, pushing, and lifting are very well possible. Two-handed operation further expands the number of simultaneously available degrees of freedom which can be mapped to controllable parameters. Early studies suggest that two-handed interaction allows considerable performance improvements [37][38].

We would like to emphasize that in the design rationale presented here, making the action more complex is not a goal in itself, as it is, for example, in designing child proof locks on bottles of detergents or medicines in which the action is made more complicated on purpose whilst the functionality to be accessed remains the same. Instead, the goal is to design actions which exploit human motor skills in order to realise more sophisticated control; control which through push button style interaction cannot be achieved. What is acceptable from a learning curve point of view, is dependent upon application and context. In any case, learning bodily skills should not be confused with memorizing menu structures or sequences of button pressing.

Examples of rich user actions

This section shows four concepts in which the richness of the user's actions contributes to usability, aesthetics or both: an interactive toy, a mobile phone, a microwave oven and a programmable heating controller.

Interactive toy

Figure 3 (video available) shows a toy called Tune-me-in (design: Marcelle Stienstra, PhD project with TU Twente/Philips Research) [39]. Children use two of these collaboratively to steer a rabbit through a maze in an arcade-style game.

Description

To play the game, two Tune-me-ins are used, one for each child. A Tune-me-in has an antenna, which senses the proximity of the hands. The antenna is divided into three parts, each of which triggers a different note and therewith changes the direction and position of the rabbit within the maze. To move the rabbit, the played note needs to be correct and sufficiently loud. The closer the hand is to the antenna, the louder the tone. However, when the hand touches the antenna a buzzer sounds and points are deducted from the score.

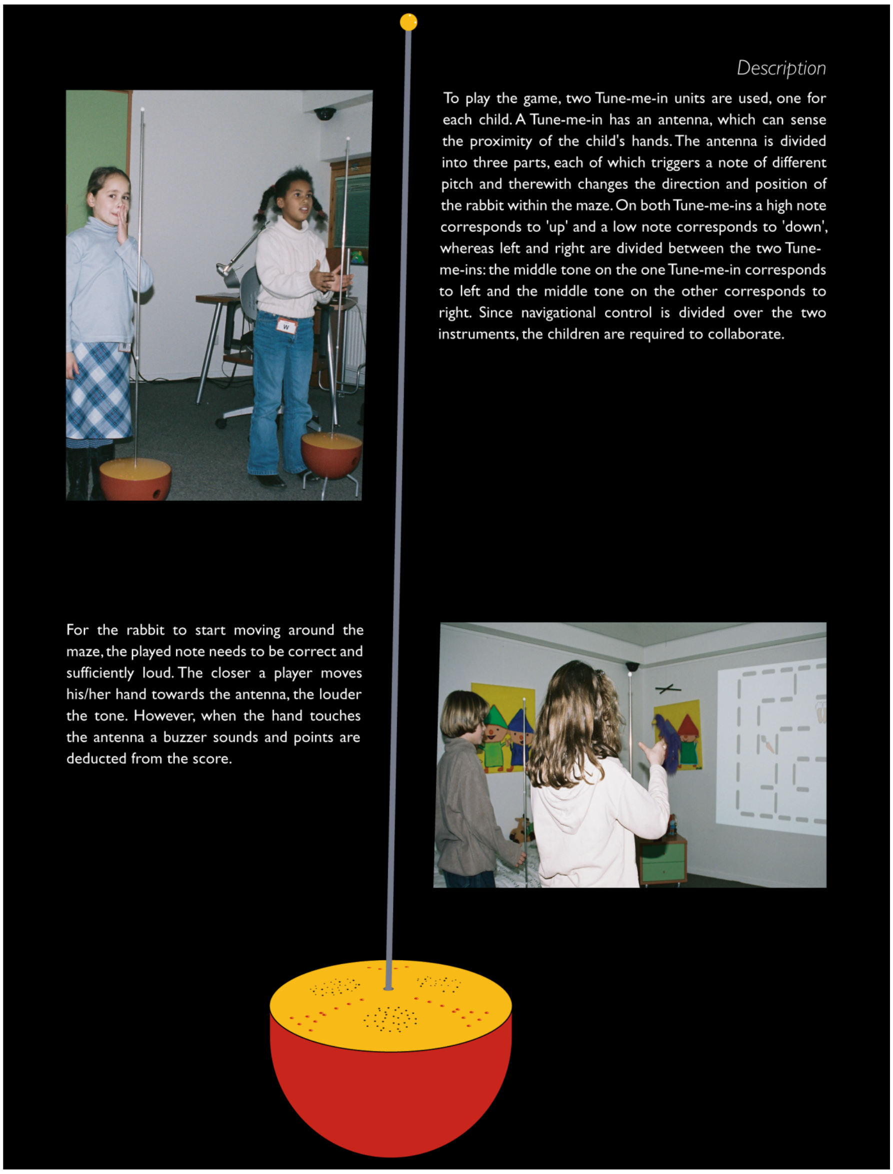


Figure 3: Interactive toy TuneMeIn

Analysis

Tune-me-in strongly depends on motor skills to be used successfully. Fine motor skills are needed to make a loud sound without touching the antenna. In addition, gross motor skills are required to reach between the different parts of the antenna.

There is considerable physical challenge in the control of these input devices. Experiments suggest that the challenging, bodily interaction leads to enjoyment, as the large majority of children prefers Tune-me-in to the traditional mouse and keyboard combination, even though the latter is easier to use and more efficient in achieving high scores [40]. Furthermore, in contrast to most other (computer) games, the interaction does not rely so much on the speed, but rather on the care and judgement with which actions are carried out. These provide children with feelings of pride of accomplishment and enjoyment during the game. The enjoyment provided by the Tune-me-in is therefore a form of interaction aesthetics and does not simply equate to ease of use [39].

Mobile phone

Figure 4 (video available) shows a conceptual design for a mobile phone (mock-up; design: Mike Jones, Bjørn Carlsen, Eng Hoo Peh & Melanie Cigler. IT Product Design students, University of Southern Denmark, 2003), inspired by the Machine Cowboy interaction style mentioned earlier.

Description

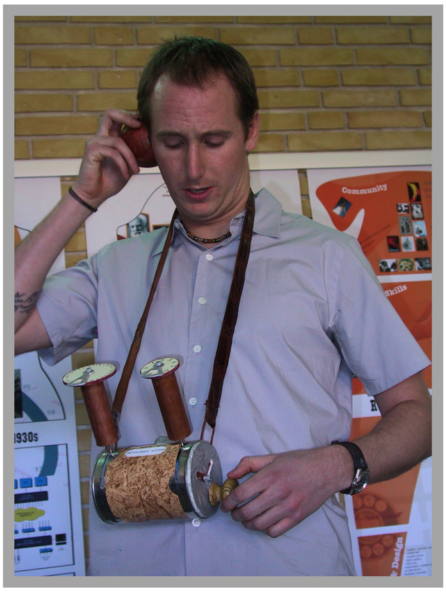
The phone features three modes: voice, text messaging and address book. Changing modes is done through a pull-out, rotating lever on the user's right, which snaps into three orientations. Taking a call is done by detaching the ear piece on the side, terminating a call is simply done by replacing it. Entering alpha-numeric characters is accomplished through two levers with a rotating dial on top. Numbers are chosen by thumbing the left hand dial, letters through the right hand dial. Once selected, a character is entered by pushing the lever forward, causing it to appear on the display. A character is deleted by pulling the lever backward.

Analysis

In this style exercise, inspiration for interaction possibilities is taken from early 20th century telephones and applied to the design of a contemporary mobile phone. The levers, the separate ear piece, and the large dials were all inspired by the wall-mounted telephones of yesteryear.

The phone makes use of a wide diversity of bodily actions, including rotation, pulling and pushing. Various hand postures are used: a full hand power grip (for the ear piece as well as the levers), a flicking thumb action (for rotating the dials) and a fine precision grip of thumb and forefinger (to rotate the mode selector). This is in sharp contrast with current phones in which nearly all functions are accessed through the same action: pushing a button.

In the final design crit of this project, the two-handedness stirred some discussion amongst students and staff. The consideration of two-handedness to speed up text input was considered laudable, considering the usability challenges with keypad based text input on mobile devices. However, the implementation of two-handedness was criticized as although both hands are used for input, their activities are not tailored to the motor strengths of each hand (non-dominant/dominant) and they are not coordinated with a view to jointly contributing to a single task. In fact, it is likely that only one hand is active at a time. Moreover, it is debatable whether the required use of two hands is appropriate for communication on the go.



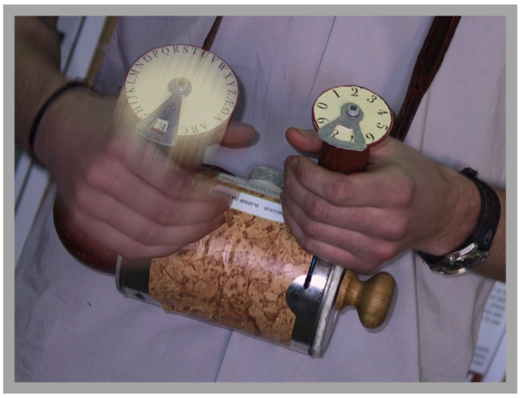
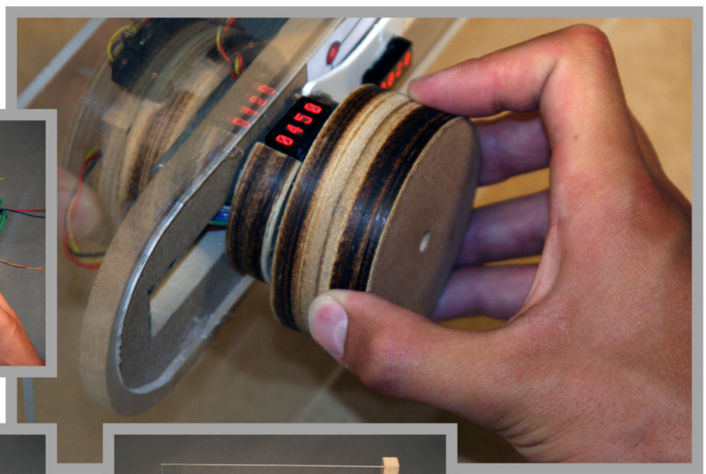
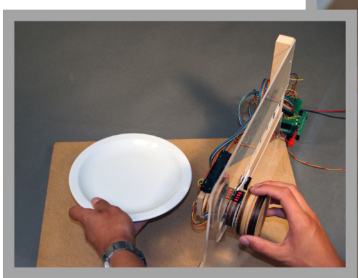
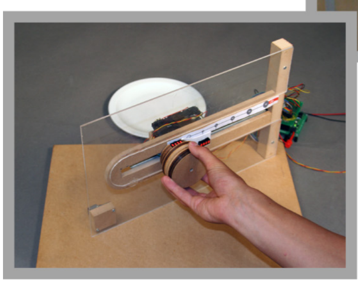


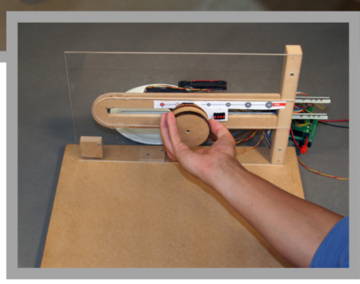
Fig. 4: Machine Cowboy Mobile Phone
design: Mike Jones, Bjørn Carlsen, Eng Hoo Peh & Melanie Cigler
IT Product Design students
University of Southern Denmark, 2003

Fig. 5: Microwave Oven
design: Rombout Frieling, ID student
TU Eindhoven, 2004









Microwave oven

Figure 5 (video available) shows a series of pictures of a conceptual design for a microwave oven (design: Rombout Frieling, Industrial Design student, Technische Universiteit Eindhoven, 2004).

Description

Mounted on the door of the microwave oven is a rotary control, which can also be slid sideways. The power setting can be adjusted by rotating the control whilst the cooking time is adjusted by sliding the control. The user can thus simultaneously set the power and cooking time as he closes the door. Two displays show the power and duration settings.

Analysis

The interaction with this microwave is characterised by simultaneous control over multiple functions. Closing the door, setting the power, and adjusting the cooking time can all be accomplished in one smooth single action.

An interesting interaction characteristic of this concept is that the design enables experienced users whilst not hampering novices. A novice may operate the device through separate actions: first rotate the dial to set the wattage, then slide it along to set the duration and finally close the door. Yet as the user becomes more skilled and fluent, the separate actions may melt into one.

Another element of skill development supported by this interface is that an advanced user may develop a physical feel—or motor memory—for how to achieve certain settings. For example, heating a cup of chocolate milk requires much rotation and a little sliding (high power, short duration), whilst thawing meat requires little rotation and much sliding.

Adjustment of parameters by physical feel may seem at odds with the accuracy that is usually associated with digital interfaces, yet such accuracy may not always be needed. For example, the tendency to adjust the cooking time accurately to the second is more an affordance of digital displays rather than a functional necessity.

Heating controller (videos available)

Figure 6 (video available) shows a programmable heating controller, which can be used to input the day program of a domestic heating system (design: Tom Djajadiningrat, Technische Universiteit Eindhoven, 2004).

Description

The controller consists of two parts, a TempStick and a TimeRule. Switching between recording and reviewing a program is done through a record button at the end of the TimeRule. When the TimeRule is slid through the TempStick with a pressed record button, a day program can be input by simultaneously operating the spring-loaded button on the TempStick. Pressing it lowers the temperature, releasing increases it. The TempStick button is solenoid-powered so that it can act as a 'display' too. When the user slides the TimeRule through the TempStick without pressing the record button, he can see and feel the fallback button move in accordance with the program.

Analysis

In this example, the bandwidth is increased by combining actions of the left hand and the right hand. In record mode, two degrees of freedom of the left hand are used: it simultaneously presses the record button and slides the time rule in analogue fashion. The right hand functions differently in record and playback mode: in the first mode the right hand indicates the preferred temperature at specific times, in playback mode, the index finger of the right hand is used to 'read' the temperature.

The input is thus two-handed. The two hands are allocated different actions and are used in a coordinated, concerted action to achieve the functionality. Even though the actions of both hands are quite simple, their combination makes the interaction much more fluent.

Figure 6: Heating controller

Output side: enriching product reactions

As we pointed out in our historical overview, movement of product components plays an ever decreasing role within interaction. Nowadays, feedback is provided mainly through displays, with the form of the product staying largely the same. Here we argue the benefits of an alternative, '4D' form of product reaction, in which both 3D appearance and movement (i.e. the appearance changing over the time dimension) are used to make the product communicate with the user. First, it is claimed that by going from 2D to 4D information the cognitive burden on the user may be lowered as 4D form can directly guide the user's actions. Second, it is argued that movement is highly expressive and can serve as a carrier of emotional information. Third, shifting the emphasis from anthropomorphic or zoomorphic appearance (i.e. products looking like humans or animals) to movement (i.e. products moving in a manner inspired by human or animal movement), allows a more abstract, product appropriate manner of expression. Product movement may not only enhance communication but may also form a new source of aesthetics. Finally, some examples are given of interaction concepts in which moving components play both a communicative and an expressive role.

From cognitive to embodied perceptual information

2D displays: cognition before action

The displays that are so ubiquitous in intelligent products today, display their information—usually icons and text—in 2D and visual form. Information displayed in such a manner has no direct consequences on our actions: the output does not really guide us in what to physically do with a product. There is a discontinuity in the perception-action loop: we have to interpret the information provided in the virtual space of the display, to then decide what physical actions to undertake in the physical world.

4D displays: perception with consequences for action

Unlike 2D graphical information, 3D physical form can be used to directly invite and guide user actions, a concept known in interaction design as affordance [17][29]. For example, a doorhandle can be shaped in such a way that it expresses whether the door requires pushing or pulling and invites the user to act accordingly.

The step taken here is to move from products with a static appearance to ones that can change their appearance over time. If we treat time as a dimension such form can be seen as four dimensional. A particularly interesting characteristic of 4D form is that it can have direct consequences for our action possibilities in the real world. By changing the form of a product, some action possibilities may literally be physically blocked whilst others are opened up. This may lead to products that can directly guide our physical actions [41].

4D form may sound futuristic, yet in a sense 4D form already exists in the form of motorised product components. Some examples of current actuated product components are ‘folding’ car wing mirrors, doors and drawers of CD players, and tape compartments of camcorders. However, such robotic elements in products generally serve purely functional purposes and are not used as a form of output which enhances the user-product dialogue.

From 2D, via 3D, to 4D: enriching expressiveness

The sensory poverty of displays and the inflexibility of 3D form

When it comes to expressiveness, 2D displays have a dual nature. On the one hand, graphic displays can provide rich visual feedback through coloured animation. On the other hand, 2D displays lack the sensory richness and expressiveness of the physical world including 3D form, material and texture [42][25].

Still, despite its sensory richness, 3D form is rarely considered as a form of output in interaction design, as it lacks the flexibility that is so characteristic for 2D displays. There are two causes for this inflexibility. Either 3D form is static and therefore has a fixed expression that is not dependent on user input. Or, if 3D form does change, the changes in expression have a fixed relationship with input, pre-determined by a product’s mechanisms. For example, the expression of the 3D form of a product may change as buttons pressed, sliders change position, knobs change orientation, spring loaded lids open or close etc. However, such output is generally not under direct control of the microprocessor. 3D form can therefore not be used to display product output in the way that 2D displays can.

4D: physical movement as a carrier of meaning

4D form, i.e. form that can change over time under control of the microprocessor, can combine some of the flexibility of 2D displays, the sensory richness of the physical world, and the expressiveness of movement.

The aesthetic expressiveness of movement in the physical world is clear from such disciplines as dance and theatre. Dancers and actors can convey emotions and character through their movements. In a specific branch of sculpture, called kinetic art, artists such as Tinguely and Moholy-Nagy explore the aesthetics of the movement of mechanical contraptions. Heider & Simmel report experiments in which personality traits and emotions are attributed to very simple shapes—such as squares, circles and triangles—dependent on their movements [43]. By bringing movement under microprocessor control, its rich expressiveness can be used both for communicative and aesthetic purposes in the user-product dialogue.

Shifting the emphasis from appearance to movement

The pitfalls of anthropomorphism in appearance

An issue that is highly topical within interaction design—in particular in the fields of entertainment robotics and emotional computing—is how products can express emotions [44]. The assumption often seems to be that for products to have an emotional expression they must be anthropomorphic or zoomorphic (Figure 7), i.e. resemble humans or animals in their bodily configuration or appearance [45][46].

It is this assumption that is questioned here, for the following three reasons. One is that such resemblance may misleadingly suggest that robotic products have the same intellectual capabilities as animals and humans, a visual promise that for the foreseeable future cannot be fulfilled [44]. The second is that it causes designers to loose aesthetic control: when appearance and movements are dominated by human or animal like bodily configurations and faces, much design freedom is lost. A third reason is that anthropomorphic or zoomorphic robots carry strong connotations, most notably of toys and science fiction, which may not be desirable for all contexts of use.

Figure 7: Anthropomorphism and zoomorphism in entertainment robotics

Qualities of movements

Whilst humans and animals clearly form a rich source of inspiration for design, biomimicry need not take place on a bodily configuration level. Perception research suggests that it is the motion kinematics and not the featural properties of the objects that are largely responsible for perceptual animacy (i.e. seeing dead matter as being 'alive') [47][48]. By mimicking the dynamic, movement aspects of humans or animals rather than their static appearance, designers may find expressions that both befit a product's 'intellectual capabilities' and are appropriate to both product and context.

A number of working prototypes, which will be shown in the next section, were built to explore the expressiveness of motion kinematics in products.

Examples of actuated, expressive product reactions

In this section, prototypes from a second year Industrial Design course at TU Eindhoven are shown. The course is called Semotion (short for Semantics of Motion) and is run in cooperation with Philips Design. It is an exercise in the expression of movement for interaction design, just as there are exercises in the expression of appearance (colour, material, texture) for industrial design. Two Semotion projects are shown here. In the first project, students had to design an object which hands the user a walnut with a particular emotion. In the second project, students had to design an object which communicates degrees of urgency. We show three designs from the first and one design from the second project..

Crack (emotion: anger; design Rombout Frieling)

Frieling describes anger as a cropped up inner tension against the outside world. When angry, one's movements become progressively faster and more powerful. Irritations may increase one's anger and, when things become too much, an outburst will follow. Frieling translated this into a design called 'Crack' (figure 8a, video available). Initially, Crack's shell is closed with only the red, serrated spaces between its blades indicating its unrest. When approached, Crack lashes out, one blade at a time, through increasingly larger movements. Finally, Crack totally opens into an aggressive angular, blood-red shape and ejects the walnut vertically.

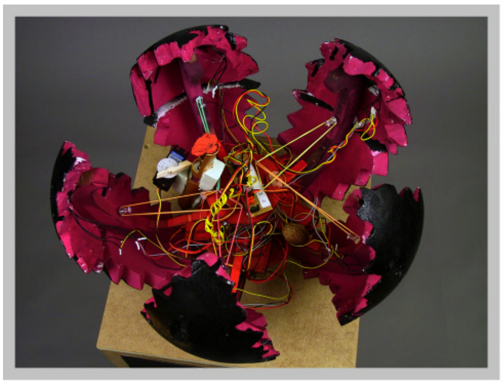


Fig. 8a: Crack (anger) — design: Rombout Frieling

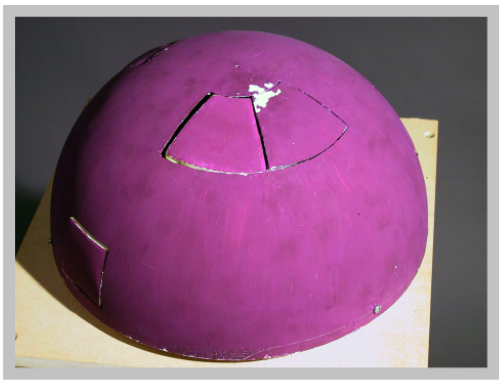


Fig. 8b: Caos (panic) — design: Dirk Volman

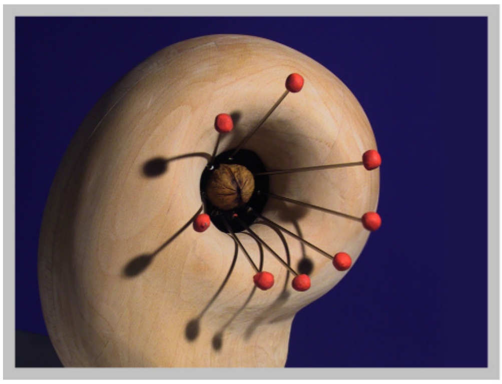


Fig. 8c: Dolly (love) — design: Jan Hoefnagels

Fig. 8d: Squabbles (urgency) — design: Wouter Walmink

Figure 8: Semotion objects

Caos (emotion: panic; design Dirk Volman)

In panic, one tries to do everything at once. Most movements are not fully completed and are followed by a counter-movement because one doubts the initial movement was effective. Volman translated these characteristics into a machine called Caos (figure 8b, video available). Caos violently moves random sections of its shell outwards and retracts them again, to finally extend all of them simultaneously. The nut rolls out in a rather uncontrolled manner and, after a short break, Caos retracts all its moving parts and comes to rest.

Dolly (emotion: love; design Jan Hoefnagels)

In showing love or affection, one can do anything from comforting, via playing with, to teasing the loved one. Hoefnagels translated love into a machine called Dolly (figure 8c, video available). Dolly exhibits smooth and slow movements, intended to resemble a comforting caress. The movements turn and topple past the user, giving an impression of teasing or nuzzling up. Eight bead-terminated pins then slowly and temptingly expand from Dolly's main body, to offer the user the walnut. Finally, Dolly goes back to sleep again.

Squabbles (urgency; design Wouter Walmink)

For physical movement to be useful in human-product communication, its expressiveness should not be limited to emotions of fixed intensity. For the second Semotion project we therefore increased the challenge by require the communication of different intensity levels of a feeling. Students were asked to design a device which can communicate urgency through its movements. To provide an imaginary context, they were asked to think of it as a device attached to an airport luggage trolley and which communicates the urgency for the passenger to get to the gate. One of the results is Squabbles (figure 8d, video available) which through the individual movements of three entities and as well as their interplay brings across different states of urgency such as relaxed, alerted, haste and panic.

Movement Analysis

From these prototypes we distilled three aspects of movement which we consider strong contributors to aesthetics of movement and which can also be found in living beings. The first is use of smooth acceleration and deceleration, instead of jerky and linear movement. The second is the use of components with multiple degrees of freedom, i.e. components that can rotate or translate over various axes. The third aspect which we consider of influence on aesthetics, is the use of superimposed movements, e.g. a rotation superimposed on a translation. Such movements can be realised through connected components whose movements stand in a child-parent relationship.

Explorative user experiment

Crack, Caos and Dolly are three of a group of five which the students evaluated in a user experiment. Users had to match each machine with one of 15 emotions, evenly spread out over Russell's circumplex [49]. Though not all designs proved successful in this user test, the ones shown here did well. Although these outcomes should be viewed with some reservation as to the experimental design, we consider the results promising and worthy of further investigation.

Discussion

Through a consideration of the role of movement within a perceptual-motor centred view on tangible interaction, this approach brings into relief a number of lingering issues in interaction design. Here we would like to share our reflections on six of these issues with the design research community.

The mind-body dichotomy

A focus on user movements requires us to consider not only our mental but also our bodily abilities. It similarly affects our view on learning, emphasising as much the acquisition of physical skill as the honing of cognitive abilities. The whole notion of skilled movement is in sharp contrast with today’s ‘button pushing’ interaction. It almost painfully highlights how 'ease of use' is commonly translated into physically trivial actions and puts faith predominantly in our mental abilities rather than our bodily skills (Strictly speaking, the philosophy of embodiment dissolves the mind-body distinction, rather than replacing the Cartesian priority of ‘mind over body’ with a similarly dualist priority of ‘body over mind’. When appropriating these ideas for design, however, the reversal of this priority may be of greater ostensive value than its dissolution.). Instead of a belief in mental models to successfully steer our actions, we may need to design for products that support the view that our understanding of the world springs from our bodily engagement with it.

Aesthetic meaning arising in interaction

By ignoring the experience that arises from physical movements, a major part of the aesthetic potential of interactive products is neglected. Whilst clearly most non-electronic products are to be physically interacted with, aesthetic considerations in industrial design have traditionally been much more about the physical appearance of products than the physical interaction between user and product. This aesthetic of appearance emphasizes the visual qualities inherent in an object, considering its aesthetics as physically disengaged from the user. Effectively, this approach to aesthetics, in which products are appraised on the basis of their 'display case beauty', reduces the role of the user to that of observer. Aesthetics of narrative takes a rather cerebral view on aesthetics of interaction, again downplaying the user's physical involvement and favouring intellectual interpretation and meaning, comparable to literary, cinematic and modern art criticism. Drawing upon embodiment, the point we make here is that not only task-oriented meaning but also aesthetic meaning arises in physical engagement. The exploration of skilled interaction suggests that the actions themselves may be aesthetically rewarding. The exploration of moving product components suggests how the expressiveness of movement is dependent on the situated, physical relationship of user and product, rather than on an object's inherent quality. The impact of product movement depends on how actor and product share physical space, e.g. whether the product's movements are directed at us or away from us.

'Digital Hacker' interfaces are disembodied

The graphical user interfaces that are near ubiquitous in today's intelligent products undervalue not only user movement but also product movement. Product movement is in fact conspicuously absent: feedback is limited to changes on graphical displays. In terms of a perception-action loop, it is not only that the repertoire of actions of the user is not exploited, but also that product movement is not used to exploit to the user's perceptual abilities. Moreover, the loop is not closed: the visual changes on graphical displays cannot directly steer our actions. As Dourish [22, p.102] puts it, interfaces can be seen as 'embodied' when they build upon our everyday experience with the physical world. Yet in the context of human-product interaction, tangible interaction has become for us much more than physicality: we consider especially promising interfaces which exploit our dexterity, which physically express their state and which close the perception-action loop by steering our actions through the product's physical reactions.

Data vs. perceptual-motor centred tangible interaction

In a previous article, we discussed the differences between a data-centred and a perceptual-motor centred approach to tangible interaction [25]. In our view, a focus on movement emphasizes the differences between these approaches. In a data-centred approach, the physical objects function as carriers or controls on virtual data, with the skills of the user and expressiveness of the movements playing a less important role. In a perceptual-motor centred approach, it is exactly the motor skills and perceptual sensitivity to the rich expressiveness of the physical world that take centre stage.

Anthropomorphic movements vs. appearance

The still popular view on interaction as a ‘man-machine’ dialogue in which the machine functions as an partner in communication, often appears to lead to interactive products, and especially robotic products, which are created in the image of mankind [50]. A focus on movement stresses the import of physical behaviour over physical appearance. Such an approach may be less stifling form-wise whilst capitalizing on human sensitivity to anthropomorphic motion-kinesthetics.

Symmetry of input and output qualities

There seems to be some correpondence in what constitutes quality of movement between the input and the output side in interaction. On the input side we mentioned 'richness of actions', the variety in the repertoire of user actions that a product allows for. On the output side, this is mirrored by the degrees of freedom that product components have. Likewise, the simultaneous degrees of freedom on the input side correspond to the superimposed movements on the output side. Finally, the sensitivity that is offered by analogue control on the input side is similar to the smooth movement we mentioned on the output side. In hindsight, this symmetry is not so surprising: as we were looking for anthropomorphic qualities of movement in product behaviour there are bound to be similarities between expressive product movement and human movement.

Implications for future work

So far, we have treated movement in input and movement in output as completely separate. The examples on the input side, such as the microwave and the children's toy require skilled input but offer conventional type output in the form of numeric or graphical displays. The examples on the output side, feature expressive movement, yet are triggered through proximity sensors with simple switch-like behaviour: once they are triggered they do their 'dance'. In the final part of this article, we point out that much of the challenge for interaction design in fact lies in the design of the coupling between the input and output movements.

Coupling physical action and reaction

Although some work has been done on coupling input and output, the emphasis has been mostly on usability. First, we cover these usability aspects of couplings, then we turn to our main interest: the aesthetic aspects of coupling.

The usability of coupling

Action-reaction coupling in electronic devices often seems to be completely arbitrary. Wensveen et al. have investigated what makes the link between action and reaction in mechanical devices (i.e. a pair of scissors) seem 'natural', in order to transfer these qualities to electronic products [51]. They identify a number of unity principles including time, location, direction, dynamics, modality and expression. For example, the coupling is perceived as natural when there is no delay, when action and reaction are co-located, share the same direction, and have the same dynamics.

Unlike mechanical devices, electronic products do not have to follow these tight coupling laws of the physical world and can therefore offer new levels of functionality. With a remote control, for example, action and reaction are not co-located and in programmable electronics action and reaction do not coincide. The downside of breaking the unity principles is that usability suffers. Wensveen argues that if action and function cannot be bridged directly through unity principles, they need to be bridged indirectly via different kinds of feedback.

Another investigation of the coupling laws of the physical world, undertaken from a perception psychology point of view, is the work of Michotte [52]. In short, Michotte investigated when two events are perceptually considered cause and effect, experimenting with several spatiotemporal factors. For example, in animations of collisions between billiard balls he varied such aspects as timing, distance and sound delay to investigate when the movement of one ball ceased to be perceived as the cause of the movement of the other.

The aesthetics of coupling

The aforementioned literature addresses mainly the *intuitiveness* of the coupling. We are also interested, however, in how the coupling between user action and reaction affects the *aesthetics* of interaction with intelligent products. We describe three potential avenues for tackling this research: (i) violation of unity principles, (ii) interaction choreography and (iii) animism.

Violation of unity principles

One starting point is to take Wensveen's framework for intuitiveness of coupling and to purposely violate the unification principles. Though he does not focus on aesthetics, Wensveen mentions in passing that "Electronic products instill moments of magic and surprise that seem to surpass the laws of nature and physical causation." This argument is also made by Svanaes and Verplank: the surprise of the seeming violation of physical laws potentially forms an aesthetic experience [53]. Our intention is to structurally violate the unity principles to investigate how such violations may trigger aesthetic experiences.

Interaction choreography

The focus of Wensveen and Michotte is on single action-reaction couplings rather than dialogues built out of sequences of couplings. Yet art forms with a strong temporal component, such as music, dance and theatre, show that aesthetic experiences are built not only upon the aesthetic qualities of a single musical bar or an isolated movement, but also on how the expression develops in a performance over time. For example, in the performing arts, the term 'arch of tension' is one descriptor as to how the expression of work unfolds. We propose to look at aesthetics in human-product interaction in a similar manner. Considering which factors in temporal development affect the aesthetics of coupling, allows us to explore aspects of interaction that hitherto have been underexposed, such as the rhythm and flow of the action-reaction dialogue.

Animism

Even though their 'actions' are mostly predetermined, intelligent products are perceived to be actors in our lifeworld and can be thought of as having a character [54]. The perceived character of the interaction is affected by the coupling of action and reaction. For example, products may be perceived as playful (reacting with superfluous movement), stubborn (reacting through an opposite movement), shy (partial, hesitant reactions) or surprising (unexpected reactions). Research on animism investigates what makes people attribute 'life' and even 'goals' or 'mental states' to dead matter [55]. Mostly, this research focuses on very simple, non-interactive, 2D computer generated displays to investigate the minimal conditions for perceptual animacy. We are interested in drawing inspiration from these findings for the design of physical, interactive products with a focus on aesthetics in animism.

Example of coupling

Figure 9 (video available) shows a kitchen drawer of which we consider the action-reaction coupling to illustrate both 'violation of unity principles' and 'animism'. When the kitchen drawer is closed, it initially bounces back to finally draw itself fully closed. In informal discussion with colleagues and friends, many confirm that they experience this interaction as striking. We would like to suggest that this aesthetic experience stems from a violation of the unity of direction principle: for a brief moment, the reaction is in the opposite direction to the action. This violation of a unity principle has the effect of surprise. Furthermore, the kitchen drawer can be seen as an example of animism. The drawer gives the impression of having a character: it is a little stubborn, momentarily fighting the user, to finally give in.

Figure 9: Action-reaction coupling in a kitchen drawer

Closing remarks

In this paper, we covered movement in user actions, movement in product reactions and speculated on the coupling between them. Having documented the increasing neglect of the body and the decreasing use of product movement, we have attempted to outline how a perceptual-motor centred view may reverse this trend. We have done this by considering embodiment and aesthetics as fundamental to interaction and by presenting a number of design examples.

It is indeed a challenge to faithfully employ theoretical insights in service of the design of interactive products, and we do not imagine that our application of them to our present design cases is entirely unproblematic. Nevertheless, this is largely uncharted territory, and these are, we feel, important and formative steps into it.

As we focused on movement, we increasingly felt that it spotlights the gap between the state of the art in interaction design and the theoretical frameworks that supposedly inform design research. That gap may be wider than we initially thought. Still, it is our hope that this article has not exacerbated the theoretical-practical divide, but also provides at least some inspiration to pursue its closure.

Acknowledgements

We gratefully acknowledge the following people: Jacob Buur of the Mads Clausen Institute for his intellectual guidance towards a ‘skills’ view on tangible interaction and for arranging funding for the colour illustrations in this article; Loe Feijs of the Designed Intelligence Group and Steven Kyffin of Philips Design for their seminal thinking on 4D form: Loe for enthusiastically providing Semotion students with crash courses on semiotic theory and microprocessor controlled servos, and Steven for his highly motivating briefing and coaching of students on design expressiveness; Ton van de Graft for technology support; Peter Peters for co-organizing the Stacked Actions assignment; Loe Feijs, Geert van de Boomen and Peter Peters for their help on the electronics of the thermostat prototype; Meindert Janszen and Jos van de Laat for the physical prototyping of the thermostat; and last but not least, our students on the IT-Product Design course of the University of Southern Denmark and the Industrial Design course of TU Eindhoven for their hard work on the examples shown and their willingness to suspend their disbelief.

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