Bi-directional Haptic Interfaces: From Indirect Interaction to Direct Interaction

Sark P. Xing
Industrial Design, TU Eindhoven
Eindhoven, The Netherlands
p.xing@student.tue.nl

Ya-liang Chuang
Industrial Design, TU Eindhoven
Eindhoven, The Netherlands
y.chuang@tue.nl

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DIS '20, July 6--10, 2020, Eindhoven,NL.
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ACM ISBN 978-1-4503-6196-5/19/03...$15.00.
DOI: https://doi.XXXXX.XXXXX/assigned-during-rightsreview

Abstract
Interactive systems are becoming more intelligent and humanized, allowing them to develop intentionality and proactively provide suggestions. However, most of the conventional designs use indirect interactions to show machines' intentions, which has three shortages: *low physical affordance; high mental effort; asymmetry peripheral-ness*; In this paper, we explore how users interact with machines' intentions tangibly, non-obstructively and effortlessly. We synthesize the attributes of variants of interfaces through analyzing related works. We consequently identify three bi-directional interfaces that couple both system's output and user's control. This insight can inspire researchers and designers in designing interfaces for tangible interactive systems with direct interactions.

Author Keywords
Bi-directional interaction; direct interaction; peripheral interaction; intentionality;

CSS Concepts
• Human-centered computing~Interaction design~Interaction design process and methods~User interface design

Introduction

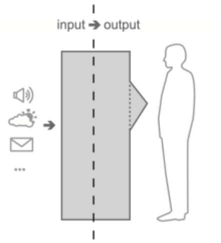

Figure 1: indirect interactions, adopting implicit input and explicit output.

Figure 2: examples of GUI and VUI in everyday activities. In A, the voice assistant notifies the user there's a visitor waiting outside over voice messages and B shows the image of the visitor on a screen.

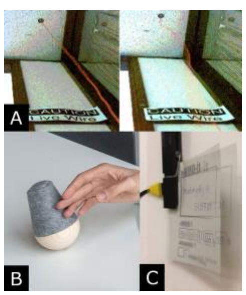

Figure 3: [A,C]:Peripheral output Dangling, Move-it; B: Peripheral Input Topplr;

As the era of ubiquitous computing unfolds, interactive systems are nowadays becoming more intelligent and humanized. They have become able to proactively provide services for users. However, these services are generally expressed in the form of indirect interactions (figure 1), meaning that the system collects data implicitly as input and output them with different means of display. Such indirect interactions have the following disadvantages: **1) low physical affordance**: the user may neither aware of their actions are being used in the form of computational data as input [8] nor has direct control of such implicit input [9]; **2) high mental effort**: common means of display (figure 2) are usually VUI or GUI based. Interacting with those interfaces always requires the user's focused attention **3) asymmetry peripheral-ness**: although some have tried to introduce peripheral interactions [10,13,15] (figure 3) to reduce the cost mental effort, they tend to address peripheral-ness either on the system's input or output but not both.

The development trend and listed disadvantages instigate us to think, "*what if everyday objects have autonomy, how would they communicate their intentions with users tangibly, effortlessly and non-obstructively?*" To answer this question, this paper investigates variants of interfaces where different interactions take place. Based on that, this paper reflects and synthesizes the attributes of these interfaces and describes three design considerations. Consequently, this study describes a set of tangible design prototypes, exemplifying both tangible user input and system output with different degrees of spatial constraints.

Reflection and Synthesis

By reflecting on related work and theories [4,9], this paper synthesizes the attributes of variants of interfaces as shown in a two-dimensional table (figure 4), categorizing interactions based on [9] and user interfaces by the user's control (encapsulating required skills, mental effort level and degree of control the

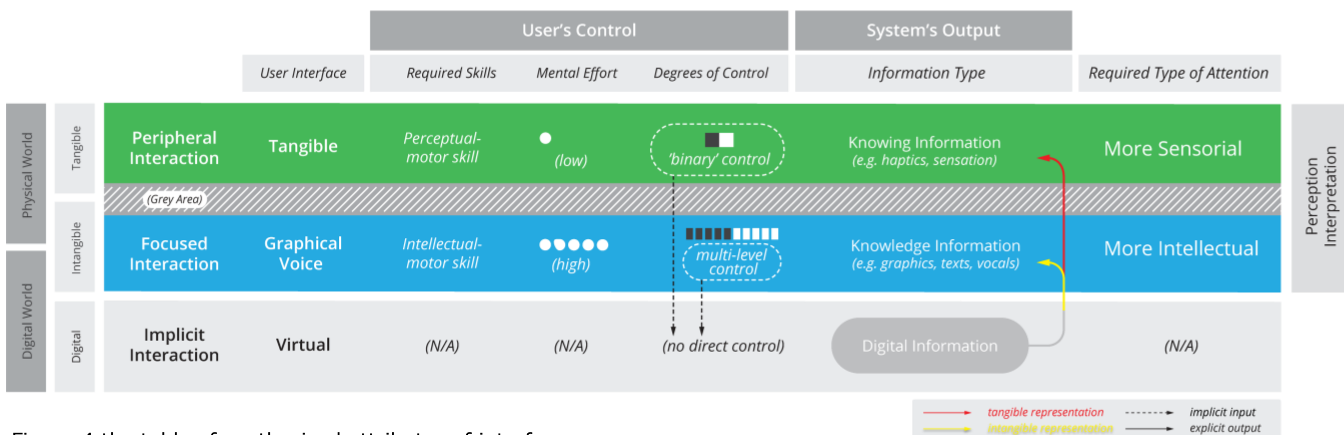

Figure 4 the table of synthesized attributes of interfaces

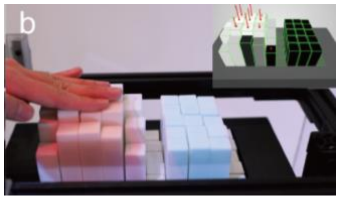

Figure 4: inForce, a bi-directional interface that can replicate captured material.

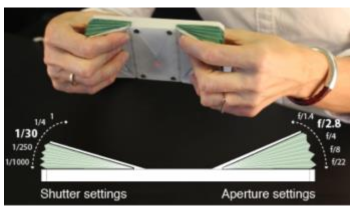

Figure 5: a bi-directional interface which can negotiate with the user via the shape of the phone.

Figure 6: Preference Canvas

interface offers), system output and required attention on the horizontal axis, as well as the way they exist on the vertical axis. Since there is no clear segment of the human's center and periphery of attention, a grey area is set in between peripheral and focused interaction, which also applies to the classification of *User Interface* as different types of interfaces may intersect each other as exemplified by [3,6], leveraging tangible pin-based shape display and projected visual augments; Furthermore, as *information type* gradually shifts from *knowing (how it feels)* towards *knowledge (what it tells)* , the required skills would consistently and correspondingly shift from perceptual-motored towards intellectual-motored. Lastly, implicit interaction usually takes place at a digital and virtual layer where humans have no direct control while it can be indirectly influenced by other intangible or tangible interfaces shown as the dash lines (figure 4).

Inspirations

This table introduces not only the overview of the internal relationship but also the in-sync and out-of-sync attributes of different interfaces. It might suggest crossover designers or researchers who are interested in the field of peripheral interactions or interface design to reflect on what input/output could have been incorporated in the designs. For instance, it might provoke ideas as mentioned in the Introduction, "*what if everyday objects have autonomy, how would they communicate (output) their intentions with users tangibly, effortlessly and non-obstructively?*" Specifically, tangible output could have been implemented on Topplr [15] (e.g. self-tumbling) to subtly suggest users skip a song that is out of the vibe; Alternatively, *binary control* (e.g. by gently patting the shaky note) could have been integrated on Move-it [13] to snooze the reminder using user's *perceptual-motor skills*.

Design Considerations

To overcome the three previously mentioned disadvantages, three corresponding design considerations for direct interactions are described as follows.

Leveraging Bi-direction

The interface should be made possible to input user's control as the way how it output and vice versa. As defined by [8], direct interactions are the user interacts consciously with the system by deforming the shape as input while the system is able to change the shape as output. For instance, inFORCE [6] (figure 5) extends inFORM [2] to detect and exert variable force on individual pins, allowing shape displays to give haptic feedback in response to the pin(s) which users press, allowing bi-directional haptic experience. Similarly, ReFlex [13] offers the possibilities for users to negotiate with the system by squeezing the shape-changing interface (figure 6) and yet it also allows the system to react back. Such shape-changing input and output based interactions allow users to communicate with systems directly and reciprocally with their perceptual-motor skills.

Exploiting Peripheral Interaction

For interactions that does not need precise (or various degrees of) control could be moved to the periphery of attention to minimize the demand of mental resources [1]. An early example called Dangling String [10] (figure 3-A), is a live wire mounted at the ceiling that subtly wobbles itself to inform office workers' the network activities. Similarly, Move-it sticky note [13]

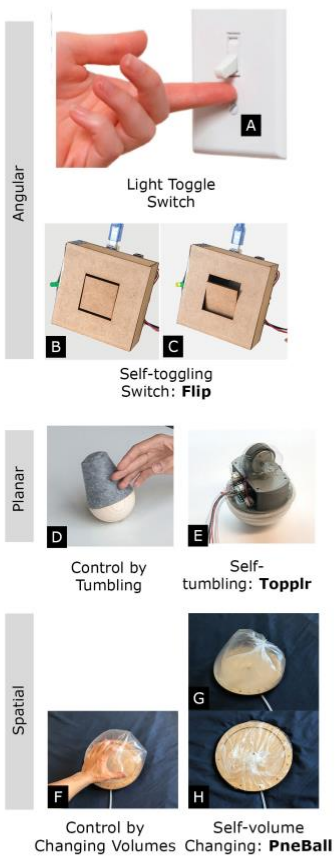

Figure 7: three examples of bi-directional interface with different spatial constraints. A: conventional tangible input; [B-C]: integrated tangible output; D: radial tangible input; E: radial tangible output; F: spatial tangible input; [G-H]: spatial tangible output;

(figure 3-C), an mechanism that actuates office sticky notes by adding motions to subtly notify users of their upcoming tasks. More recent examples include Topplr [15] (figure 3), a music controller which allows users to skip a song by tumbling.

Emphasizing Symmetry Peripheral-ness

This study argues to consider the peripheral-ness on both input and output of the interface, offering effortless control and presenting information subtly which allows users to perceive in their periphery of attention. However, it seems many interfaces where peripheral interactions take place by far only cover their peripheral-ness either on input or output but not both. For example, there is no way for Topplr to output information in one's periphery of attention as Dangling String does, and vice versa. Besides, despite the fact that Move-it incorporates both outputs (*subtle motions*) and inputs (*setting reminders*), writing and setting a reminder still demand a person's intellectual-motor skills instead of their perceptual-motor skills.

Ideations and mechanism

To cover all design possibilities, mechanisms of tangible input derivatives are explored. Inspired by Mecha-magnets taxonomy [14], resembling mechanisms are grouped by the utilized number of axis to keep good consistency with 'level of control'; Since from the prior explorations, some cases [5,11,12,16] are volume-changing or shape-changing which 3 axes are involved, so another subgenre named *spatial* is appended as an addition. Based on that, potential tangible outputs for each sub-genre are explored and ideated (figure 8), namely:

1) Self-toggling Switch: *Flip*, consisting of an actuation mechanism and a sensor on the lever. In this concept, assuming that Flip is context-aware, it knows when it is suitable to turn on the light and when it is not. The lever can flip outwards or inwards to suggest turning on or off the LED.

2) Self-tumbling Topplr: *Topplr*; It could also have had subtle output as well. It can tumble itself down to notify users skip a context-unmatching song, as consistent as what it meant to be for the tumbling.

3) Self-volume Changing: *PneBall*, a volume-changing interface, aims to explore spatially related control, resembling Canvas [7], an interface that allows users to draw the area to which they expect the light setting (e.g. temperature, luminosity) applies (see figure 7);

Conclusion and future work

This study finds the disadvantages of indirect interactions in digital devices and reveals an unexplored area of peripheral interaction; It presents a table introducing the attributes of different interfaces for a full spectrum of interactions; It describes three considerations for designing interfaces that integrate intuitive user control could be coupled on tangible interfaces for the unfolding future. Yet, more substantial user study of the table of attributes are needed to evaluate its clarity and objectiveness; The user experience of three ideated prototypes regarding intentionality, usability, obtrusiveness, etc. should be evaluated; Application scenarios should be more elaboratively articulated for better understanding.

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