RWTH AACHEN UNIVERSITY

Design Implications for the Recognition of Different Uses of Everyday Objects

Bachelor's Thesis at the
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Registration date: 2014-05-29
Submission date: 2014-10-27

I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed, and that I have marked any citations accordingly.

Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie Zitate kenntlich gemacht habe.

Aachen, October 2014
Christian Humme

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Abstract

The goal of this Bachelor's Thesis is to investigate whether there are ways to discriminate between a normal use of everyday objects and their repurposed use as Tangible User Interfaces based on how they are manipulated. Current systems mainly rely on the use of modes, either by requiring special devices or gestures, by employing timeouts, or by limiting the interaction spatially.

This thesis focuses on object affordances: do objects have unused affordances, that do not play a role in the usual way of interacting with the object but do effect the repurposed use? Hence, are objects approached and handled differently when being repurposed? If such differences existed, these could then be used to implicitly discriminate between the normal use and the repurposed use of everyday objects. This could facilitate the repurposing of everyday objects as user interfaces by making explicit mode switches redundant.

To answer this question, two user experiments were conducted. In the first one, users were presented different everyday scenarios and asked to handle typical objects for these scenarios both in the normal way and in a repurposed way as a tangible controller. We observed these interactions and tried to find differences, and whether these could be used to decide implicitly and without the need for explicit mode-switching, if an object is currently being repurposed or not. The second user experiment focused on the objects, that showed the most promising results. The observation was narrowed down to the initial contact points of an interaction.

The touch patterns we observed were ambiguous. Initial contact points as an exclusive differentiator would produce many errors, even for the most promising objects we looked at. We concluded by inferring design implications for repurposing everyday objects from our research.

Überblick

Das Ziel dieser Bachelor-Arbeit ist es herauszufinden, ob es Möglichkeiten gibt zwischen normalem Gebrauch von Alltagsgegenständen und ihrer zweckentfremdeten Benutzung als greifbare Benutzerschnittstelle zu unterscheiden, basierend auf der Art wie sie gehandhabt werden. Gegenwärtig sind Systeme auf Modi angewiesen, sei es dass sie spezielle Geräte oder Gesten einsetzen, Timeouts verwenden oder die Interaktion räumlich einschränken.

Der Schwerpunkt dieser Arbeit liegt hierbei auf dem sog. Angebotscharakter (engl. *affordances*) der Gegenstände: besitzen Objekte unbenutzte affordances, die im alltäglichen Gebrauch keine Rolle spielen, aber ihre Zweckentfremdung beeinflussen? Werden Gegenstände somit anders gehandhabt, wenn sie zweckentfremdet werden? Falls solche Unterschiede existieren könnten sie genutzt werden um implizit zwischen normalem und zweckentfremdeten Gebrauch zu unterscheiden. Dies könnte die Zweckendfremdung von Alltagsgegenständen als Benutzerschnittstellen erleichtern, indem es explizite Moduswechsel überflüssig macht.

Zur Beantwortung dieser Fragen wurden zwei Studien durchgeführt. In der ersten wurden den Versuchspersonen verschiedene alltägliche Szenarien präsentiert, in denen sie typische Objekte sowohl normal benutzen sollten, als auch zweckentfremdet als greifbare Benutzerschnittstelle. Durch die Beobachtung dieser Interaktionen wurde versucht Unterschiede zu finden, sowie deren Eignung implizit und ohne die Notwendigkeit eines expliziten Modus-Welchsels entscheiden zu können, ob ein Gegenstand gerade zweckentfremdet wird oder nicht. Die zweite Studie konzentrierte sich auf die Gegenstände, welche die vielversprechendsten Resultate gezeigt hatten. Die Beobachtung wurde auf die initialen Kontaktpunkte einer Interaktion eingeschränkt.

Die beobachteten Berührungsmuster waren mehrdeutig. Initiale Berührungspunkte als alleiniges Unterscheidungsmerkmal würden viele Fehler produzieren, selbst bei den vielversprechendsten Objekten. Wir enden, indem wir Designleitlinien für die Zweckentfremdung von Alltagsgegenständen ableiten.

Acknowledgements

To all people who supported me in one way or another: thank you!

"A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools."

—Douglas Noel Adams (1952–2001) in "Mostly Harmless" [1992]

Conventions

Throughout this thesis the following conventions are used.

Text conventions

If nothing else is stated, all work in this thesis was done by myself, but for aesthetic reasons everything is written in first-person plural perspective.

Male pronouns are used when talking about users, independently of the real gender of the user.

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition:
Excursus

The whole thesis is written in American English.

Chapter 1

Introduction

In current human–computer interaction (HCI) research, various objects are used as Tangible User Interfaces (TUIs). This concept can be explained as follows:

TANGIBLE USER INTERFACE (TUI):
Tangible User Interfaces were pioneered by Ishii and Ullmer [1997], who introduced them as a new type of human-computer interaction, which couples digital information to everyday physical objects.

Definition:
Tangible User Interface (TUI)

These TUIs make otherwise virtual things graspable, allowing completely new interactions with them. The Reactable[1] (see Figure 1.1) is a prominent example, which is an electronic musical instrument with an intuitive tangible interface. By manipulating real objects on the desktop surface of the Reactable, music can be played and sound can be changed in real time. The resulting wave forms are directly displayed on the table, thus making music a visible and tangible experience.

TUIs make otherwise virtual things visible and graspable.

To utilize these advantages, everyday objects could be repurposed as tangible controllers. As an example, these repurposed everyday objects could be used as shortcuts to control a PC [Cheng et al., 2010]. Since a dedicated device

Repurposed everyday objects could be conveniently used as TUIs.

[1] http://www.reactable.com/

Figure 1.1: The *Reactable* is a prominent example of a TUI. Music can be played and changed by physical objects placed on the surface.

would not be needed, these improvised TUIs could benefit everyday life by conveniently offering remote controls for otherwise stationary interfaces, extracting the most used functions of an interface to provide a simplified controller, or even duplicating controllers. Some methods make use of physical characteristics of the objects to further enhance the user experience by exploiting existing tactile properties for passive haptic feedback for virtual controls [Henderson and Feiner, 2008].

We imagine a smart room, that is able to track objects and interactions on them.

As a basis for our research, we imagine a smart room, which is capable of tracking the user and objects in the room, as well as interactions on these objects. Instant User Interfaces [Corsten et al., 2013] presents a marker-free technology to track objects and recognize interaction with them. With such tools at hand, we can track objects and detect touches without the need for preparation (given the object's 3D model is known), thus enabling us to use any everyday object as an Instant User Interface (Instant UI).

The main problem is the distinction of normal use and repurposed use as a controller.

Because such a repurposed everyday object still has a valid normal use, the main problem of creating a reliable Instant UI would be to correctly interpret the user's intention. Every time a user interacts with the repurposed object, a decision has to be made if the object is currently used as a controller or just as the original everyday object. A wrong decision could either lead to a missed command (false negative) or to unintended commands (false positive), both of which would negatively impact the user experience.

The concept of our approach is explained in the next chapter.

Chapter 2

Concept

The main problem when repurposing everyday objects as tangible user interfaces is the distinction between normal and repurposed use, as described in the previous chapter.

Most current systems use modes to differentiate between normal use and repurposed use.

2.1 Modes

The definition of an interface including modes was given by Jef Raskin:

MODE:
"A human-machine interface is modal with respect to a given gesture when

1. the current state of the interface is not the user's locus of attention and
2. the interface will execute one among several different possible responses to the gesture, depending on the system's current state." [Raskin, 2000, p. 42]

Definition:
mode

The most prominent example of a mode would be the *caps lock* key on the computer keyboard, which switches into and out of the mode, in which all entered characters are capitalized.

The user has to keep the current mode in mind.

When using a modal system, the user has to remember the mode in which the system currently is to get the desired results of his actions. A better solution are quasimodes, also introduced by Raskin [2000], which he describes as modes that require conscious actions to be maintained. Examples are the *caps*, *ctrl* or *alt* keys, where the mode is enabled only as long as the user actively presses the keys. Wearing special devices (compare Figure 2.1) can be considered a quasimode, since it is unlikely to forget wearing it.

Modes are likely to produce errors, we try to avoid them by implicit mode-switching.

We try to avoid explicit mode switches, since these are likely to produce errors. Our approach targets on implicit mode-switching. Ideally, the user's intention should be correctly predicted based only on the interaction context itself. Thus it is necessary to determine whether differences between normal use and repurposed use of everyday objects as tangible user interfaces exist, and if these could be used to reliably predict the user's intention.

We try to find these differences by looking at the affordances of everyday objects, which we want to repurpose as tangible controllers.

2.2 Affordances

Originally, the term *affordences* referred to all possible actions in the environment in relation to the abilities of the subject.

The term "affordance" was first introduced by psychologist James J. Gibson in his article "The Theory of Affordances" [1977], where he used it to describe all possible actions in the environment in relation to the abilities of the subject. A wooden chest would have the affordances to be pushed, pulled, sat on, thrown and opened (amongst lots of others), whether the subjects is aware of all this or not, simply because technically he would be able to do so.

The most common meaning of the term "affordance" relating to the field of human–computer interaction (HCI) was

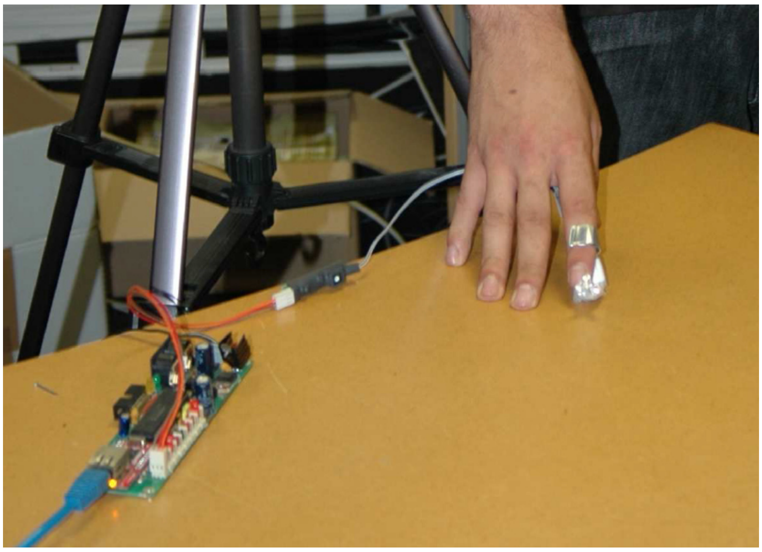

Figure 2.1: *Opportunistic Music* [Hachet et al., 2009] uses a combination of vision-based 3D-positioning and a worn device to detect touches to control music.

formulated by Donald A. Norman in his book "The Design of Everyday Things". He changed the concept by making it relational:

Definition:
Affordances in HCI

AFFORDANCES IN HCI:
Affordances are described as "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used." [Norman, 2002, p. 9]

Thus the original breadth of all possible actions gets limited to those a subject would perceive.

Affordances vary between subjects.

While it is technically possible to write on a football, the perceived affordance would be more likely be to *kick*. These perceived affordances can be influenced by past experiences and vary between subjects. Although a chair can be thrown, the most common affordance would be to *sit*, because not only does the ergonomic shape of a chair usually suggest sitting, but most people would also be used to sitting on chairs instead of throwing them.

Unused affordances are uncommon ways an object could be used.

Since throwing a chair would still be an affordance, although a more uncommon one, the affordances of objects could be ranked by the probability they will be used. This ranking would be different for each individual subject and also change depending on the situation, but you could still coarsely categorize them into "used" and "unused" affordances.

We propose that these unused affordances affect the repurposed use of everyday objects. Apt examples are:

- A turning-knob for volume control could be replaced by a glass on a table, because it is round and can be turned.
- The push-button of a door-opener could be replaced by a ballpoint pen, because it also has a push-button.
- A light switch could be replaced by a stapler, because it also can be pushed.

2.3 Other Methods

Objects are repurposed as controllers for convenience.

Convenience would be a common reason to repurpose everyday objects as controllers. People could quickly replace a dedicated input device that is out of reach or missing, or create shortcuts to frequently used commands of existing input devices.

Alternative input methods like voice- or gesture-recognition become more popular.

Other alternative input methods are, e.g., speech-based interfaces or gesture-recognition interfaces. With the iPhone 4S, Apple introduced Siri[1] to a broad consumer market in 2011. It acts as an intelligent personal assistant and can be accessed through a natural language user interface. Microsoft introduced voice and gesture input to the Xbox One[2] in 2013 through the Kinect system. These examples show, that working systems already exist and help to increase the acceptance of alternate ways to control systems.

[1] https://www.apple.com/ios/siri/
[2] http://www.xbox.com/en-US/xbox-one/innovation

Nevertheless, speech-based interfaces are problematic, since they're most usable when alone. When other people are around, they could either hamper the recognition process by speaking and thus creating interference or they are disturbed by the speech commands, for example in a quiet working environment. Voice commands issued at an invisible receiver can also be irritating to other conversational partners, especially when talking on the phone.

Disadvantages of speech-based interfaces are interferences by noise and annoying other people.

Similar issues arise with gesture-based interfaces. While it can be socially awkward to make strange gestures around other people, a special alphabet of gestures for certain commands would have to be learned. Depending on the gestures used, it could also diminish the convenience aspect we aim for.

A disadvantage of gesture-based interfaces is the need to memorize special gestures associated to commands.

2.4 Benefits of Implicit Discrimination

Our approach tries to combine the advantages of tangible user interfaces with the availability of everyday objects, while reducing the possibility of errors by removing explicit mode switches. While our approach is based on objects in the user's vicinity, we assume that some common objects are always present. We envision a system that does not require any special device or long preparation of the objects, so any object could be used as an Instant UI without much effort.

We try to combine the comfort of haptic feedback with the convenience of instantly available controllers.

This new implicit approach could greatly enhance comfort for the user, because it would improve the following aspects:

- The user could handle a physical object providing haptic feedback, which would allow reliable eyes-free interaction.
- The user would not have to remember modes ("Can I safely drink from the cup now, or would that turn off the lights?")

- The user could choose replacement items that resemble the original device in terms of affordances and thus could be used in almost the same well-known way. (If these affordances overlap with the normal use of the object, different gestures or gesture sequences could still be used to distinguish normal from repurposed use.)
- The user would not be restricted to certain dedicated devices.

In the following chapter we will have a look at current research and how the problem of mode switching is solved.

Chapter 3

Related Work

In the previous chapter we stated the main problem for repurposed everyday objects, that are used as tangible user interfaces: the discrimination between the normal use and the repurposed use as a controller. We will have a look at other approaches and evaluate their methods of differentiation. We are especially interested, if these systems utilize (unused) affordances.

3.1 Opportunistic Controls

Opportunistic Controls project virtual controls onto physical objects to provide haptic feedback in AR.

As a first example, we have a look at *Opportunistic Controls* (OC) by Henderson and Feiner [2008]. They propose "a class of interaction techniques for augmented reality (AR) applications that support gesturing on, and receiving feedback from, otherwise unused affordances already present in the domain environment." [Henderson and Feiner, 2008, p. 1] The propose a scenario, where a mechanic is servicing a turbine engine. This constrains the space for additional devices and limits the freedom of possible interactions. Here, the virtual input devices are projected onto physical surfaces that share affordances with the real input device simulated. A metal knob is used as a virtual button because of its form, a flexible tube with grooves substitutes a physical slider.

Figure 3.1: Opportunistic Controls [Henderson and Feiner, 2008]: Example for virtual controls aligned with physical characteristics. Left: virtual buttons on raised parts of an engine housing. Right: virtual slider on a wiring harness with grooves.

Their prototype uses a head-worn display with two cameras, optical markers and a separate camera for gesture recognition.

Their prototype features a semi-transparent head-worn display with two cameras. The OC widgets get positioned next to an optically tracked ARTag fiducial array (compare Figure 3.1). The gesture recognition is performed using a single overhead camera, enabling eyes-free interaction with the virtual controls but also limiting the possibility do differentiate between hovering and touching gestures.

Unused affordances are the basis for placement of OC widgets.

This system is basically designed to utilize unused affordances to enhance interaction with virtual controls. Although they envision an approach that does not require modifications of or additions to the task domain, it is specially created for augmented reality use and thus requires a specialized AR device.

Furthermore, since AR controls are laid over the normal features, this system does not support the normal use of these features: the virtual control would always get triggered.

3.2 iCon

iCon uses pattern stickers and a webcam to turn objects into input devices for a computer.

Another example for a system, that repurposes everyday objects as tangible controllers, is *iCon* by Cheng et al. [2010]. It uses pattern stickers and a web cam to turn objects into auxiliary input devices to control background tasks for desktop applications. They propose, that such a system would make context switches unnecessary for

The system consists of a webcam and pattern stickers that are applied to everyday objects (compare Figure 3.2). Since some objects, e.g. drinking vessels, do not have flat top side to put these stickers on, the webcam can either be installed in eagle-eye view or under the desk with a transparent desktop, which can then recognize pattern stickers applied to the bottom side of the objects. These pattern stickers can then be visually tracked to recognize movement or rotation of the enhanced objects.

The system can be installed in eagle-eye view with pattern stickers on top of objects, or under the desk with the pattern stickers on the bottom of the objects.

The system can distinguish between click, rotate, and drag gestures. Rotating and dragging are executed by moving the object on the desktop surface. Click is done by either shortly covering the pattern sticker, or by lifting the object from the surface, depending on the installation of the system. Certain commands can then be mapped to each object and each interaction. Examples for binary commands (clicking) are: toggle play/pause for a music player, or mute/unmute the sound output. Examples for consecutive control (rotating or dragging) are: zooming in and out while browsing photos, or scrolling in a web browser.

Gestures recognized are rotating, dragging and clicking.

A time-to-live mechanism with two thresholds is used to distinguish between a command and normal use of the object, as well as to remove the controller from the system. If the controller disappears from the view of the webcam, a timer is started. If the object returns within a short time, this is interpreted as a click, otherwise no command is issued. If the object is gone for too long, it is released from the system and does no longer act as a controller. This also implies, that rotating and moving the object would always be interpreted as a command.

A time-to-live mechanism is used to differentiate between normal use and repurposed use as a controller.

The user would have to keep these timeouts in mind when interacting with the object, since for the normal use it would be necessary to first cover up the pattern sticker to prevent wrong commands. If the normal use takes too long, e.g. when refilling a coffee mug, the object has to be reintroduced to the system as a controller.

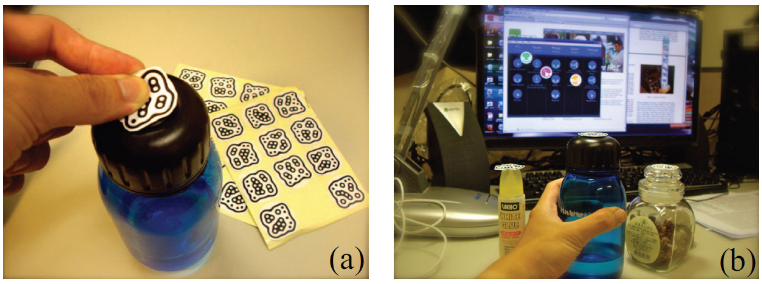

Figure 3.2: iCon [Cheng et al., 2010]: (a) An everyday object is equipped with pattern stickers, that can be recognized by a webcam. (b) Different controllers can be mapped to different commands.

Unused affordances of the objects are not specifically utilized.

Although *iCon* can turn everyday objects into tangible controllers, their respective affordances do not play a major role in the process. The only exploited properties are the potential of being turned, dragged and lifted up, which can be done with most everyday objects usually found around computer workplaces.

3.3 WorldKit

WorldKit uses a smart room to project virtual displays or controls onto surfaces.

The creation of interactive surfaces in a smart room is explored by *WorldKit* [Xiao et al., 2013]. Using a projector and a depth-camera, user interactions on any surface can be recognized. New virtual interactors can be created by a swiping motion on a surface. A pre-programmed *interactor* is then bound to it, which could be a linear slider, an object counter or a indicator for percentage covered.

The virtual controls and displays can interact with each other.

Combining these interactors makes it possible, e.g., to project a schedule onto a door, when it is closed. A user sitting on the couch in front of a TV could trigger the projection of a digital TV guide and a volume control on the table in front of him, as well as a virtual slider to dim the lights on the arm rest next to him (compare Figure 3.3).

Everyday objects are not repurposed, only flat surfaces.

The *WorldKit* system focuses on flat, stationary surfaces. While these are usually present in an everyday scenario

Figure 3.3: WorldKit [Xiao et al., 2013]: Virtual Controls can be placed on any surface and interact with each other. Here, a digital TV guide and a volume control are displayed on the table as well as a virtual slider to dim the light on the arm rest of the couch.

through walls and furniture, no other affordances are utilized. Also, no other tactile feedback other than *touch* is exploited.

No discrimination between normal use and repurposed use is done.

While active, the normal and repurposed use would always interfere. Just sitting down on the couch would then always show the volume control, whether the user wants to use it or not. In this case, it would even limit the space available on the table.

3.4 LightBeam

LightBeam uses a pico-projector and depth camera to turn any surface into an interactive screen.

LightBeam [Huber et al., 2012] combines a pico-projector and a depth-camera into a highly mobile device, that can enhance physical objects by projecting information on them, recognizing touches on them as well as to react to objects moving into, inside of and out of the projection area.

The fineness of information displayed can be coupled to the available surface area.

This basic setup leads to some interesting techniques of interaction. The visualization can be adapted to the size of the surface: With the information from the depth camera, the degree of detail of the information displayed can be chosen according to the available space. When a sheet of paper is gradually lifted into the projection space, the projected text changes from headline to abstract to full text, depending on how much area of the sheet is visible.

Classes of everyday objects with similar affordances can be repurposed as TUIs.

Everyday objects can also be repurposed as tangible controls. For example, a mug can be rotated to switch the information displayed from a photo stream to a website. The system uses similar classes of affordances, such that any object, which affords rotation, can be used as tangible control. The mug in the example could be replaced by a water bottle.

Documents can be scanned and browsed in a virtual stack.

The system can also be used as a visual scanner: documents held in front of the camera are captured and stored in a virtual stack in the beam. These captured objects can then be browsed spatially, by changing the distance of the display surface to the projector.

Objects inside the projection area are always considered to be repurposed.

The discrimination of non-augmented and digitally augmented use is done by spatial placement: objects moved into the projection area are always considered tangible controllers. This also limits the space available for normal interaction with everyday objects, especially considering the scenarios proposed for this highly mobile system. For example, when using this system in a cafe (compare Figure 3.4), the available space is already relatively small.

3.5 Instant User Interfaces

Instant UIs allows the impromptu use of everyday objects as temporary replacements for dedicated input devices.

The concept of *Instant User Interfaces* (Instant UIs) was introduced by Corsten et al. [2013]. The term refers to two aspects: *to instantiate* and *instantly*. Instant UIs can be seen as instances for existing dedicated interfaces, while it should also be possible to create them instantly, by repur-

Figure 3.4: LightBeam [Huber et al., 2012]: A pico projector and a depth camera turn objects into interactive displays that react to touch input.

posing everyday objects. Such improvised and ubiquitous controllers would exploit existing affordances of the repurposed objects, since interactions could be easily mapped to objects with similar affordances as the dedicated controller.

Different benefits of such a system are suggested:

Mobile controllers could be created or duplicated, shortcuts could be provided, and missing dedicated devices could be replaced.

- Convenience: it would be very comfortable to create a mobile controller instead of having to use a stationary one. A dimmer switch on the wall could for example be repurposed by a mobile everyday object that also affords rotating, like a drinking vessel.
- Improvisation: If a dedicated controller is missing, it could quickly be replaced by an repurposed everyday object. A misplaced presentation remote can immediately be replaced (compare Figure 3.5).
- Providing shortcuts: Selected functions could be outsoured from dedicated devices to create controls with higher usability. If the only functions used on the TV remote are *channel up/down* and *volume up/down* but much easier accessible controller with only these functions can be created.
- Duplication: It is possibile to multiple instances of a controller. This could be used to instantly play multi-

player video games with friends without the need to buy additional controllers.

Instant User Interfaces provide a marker-free 3D-tracking method, which can identify touches on tracked objects.

To create such Instant UIs, a reliable, marker-free object tracking solution is presented, which is able to detect object pose and touches on the surface based on an initially provided 3D model. The system uses the image of a single depth camera to track a solid object. The virtually rotated 3D model is compared to the depth image to initially find the object, which takes several seconds. Once found, the search is limited to the proximate space of the last known position, which allows real-time tracking. The tracking system is also capable of detecting touches on the surface of the tracked object. This way objects can be repurposed as tangible user interfaces.

Only a single solid object with a pre-known 3D model can be tracked. The object can get lost by occlusion or too quick movement.

The system however is limited in certain aspects. Tracking is only possible for one solid object, for which a 3D model must be provided. Losing track of the object by full occlusion or very fast movement only recovers if the object is moved back to "last known" region. Since only one camera is used, occluded features of rotary-invariant models or touches on the far side of the object cannot be tracked.

Normal use of Instant UIs is not considered.

Once repurposed, interaction with the repurposed object is always considered a command. The normal use of the object would always trigger the mapped function.

3.6 Summary

Three methods explicitly make use of object affordances.

Affordances are explicitly used by three of these systems. *Opportunistic Controls* (p. 11) and *Instant User Interfaces* (p. 16) emphasize on object affordances, to map the original interaction to objects with similar affordances. *Light-Beam* (p. 15) makes use of classes of objects with similar affordances. In the example these were round objects that can be turned. *iCon* (p. 12) focuses on everyday objects in the vincinity of desktop computers. Affordances are not specially mentioned, though to make use of the possible interactions it should be possible to move, turn and pick up

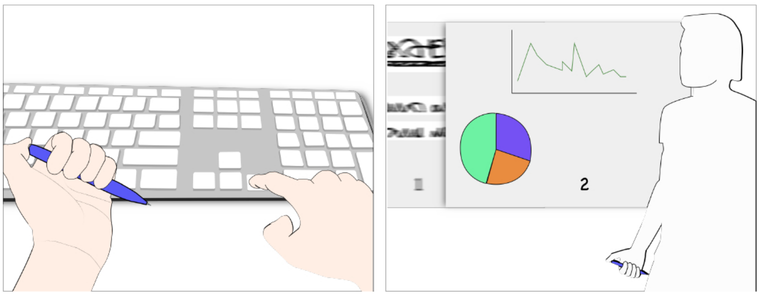

Figure 3.5: Instant User Interfaces [Corsten et al., 2013]: The interaction with a presentation remote is similar to that of a ball-point pen (clicking), which is why it is chosen to get repurposed. With a programming by demonstration technique, the pen is linked to the *next slide* command. It can now replace a presentation remote.

these objects. The only affordance used by *WorldKit* (p. 14) is a flat surface.

None of the evaluated methods make use of implicit mode switches.

Only two of the presented systems offer explicit mode switches: the *iCon* system uses a time-based approach while the *LightBeam* system uses spatial constraints. The other three systems offer no way to use the repurposed object normally, without interfering with the repurposed use.

In this context, our concept of implicit discrimination between normal and repurposed use could greatly benefit such systems in the future.

Chapter 4

Preliminary Study on Differences in Handling Everyday Objects

To be able to implicitly discriminate between normal and repurposed use of everyday objects, we have to find differences in their handling.

4.1 Research Questions

We formulated these initial research questions:

- Are there distinguishable differences in the handling of everyday objects when they are repurposed as an instant user interface to when they are used for their normal intended purpose?
- Could these potential differences be used by a system to reliably discern the user's intentions implicitly?

Figure 4.1 shows an example of such differences. When the user wants to use the mug normally, namely to drink from it, he always grabs the handle. When he wants to repurpose it as a rotary controller, he grabs the top rim. In this

Figure 4.1: These pictures serve as an example for potential differences when using everyday objects normally or repurposing them as tangible user interfaces. On the left, the user grabs the handle of the mug to drink from it. On the right, the user repurposes the mug as a rotary controller and grabs the top rim.

example, the distinction would be very clear, since different affordances would be utilized which results in very different interactions.

To answer our first research question, we had to observe users interacting with everyday objects. We did this by conducting a user study.

4.2 Study Design

Users were introduced to the concept of repurposing objects as TUIs.

Since most people would not be used to repurpose everyday objects as tangible controllers, we introduced the concept to each user at the beginning of the study. We also claimed, that this study was used to validate our scenarios, especially our choice of tasks and objects. This was done to prevent biased interactions, where the users would unconsciously change their behavior because they feel observed. As a reference, we have included the Informed Consent Form in the appendix (A.1), which every user had to sign.

Scenarios were chosen to observe the interaction with certain objects.

We decided to limit the scope of the research to a few common scenarios, in which the users were presented suitable everyday objects as well as typical tasks. These tasks were either normal ways of using everyday objects, or tasks that involved repurposing everyday objects as controllers.

Three scenarios were chosen to serve as different situations, in which repurposing would be beneficial to the user:

- Office
- Living room
- Taking a bath

The office scenario was chosen as a very common scenario to repurpose everyday objects (see 3.2 "iCon"). To contrast the office scenario, we chose the living room scenario to include different objects and tasks. The convenience aspect is very clear for the taking a bath scenario, where it is very annoying to get out of the water, e.g. to turn on the lights. The possibility to use the original dedicated device is also narrowed down, because not all controls are waterproof. However, this scenario has a more limited pool of available items.

The scenarios were selected to reflect a wide range of objects and tasks.

We chose the tasks involving repurposed everyday objects to closely match the original interaction with the dedicated device in terms of affordances. For example, we tried to replace buttons by objects that can be pushed.

The settings for the scenarios were then created using typical representatives for objects commonly found in these domains. The commands for the user were given in a story-like way, both to give the user a realistic reason to use the object in the demanded way, and to make the interaction less conscious. An example of such an instruction would be: "It is getting a little too dark to read and you do not want to get uo and walk to the door. Please push the stapler to switch on the lights." The sequence of commands was randomized to counterbalance any learning effects and the instructions themselves were kept as rough as possible.

Instructions were given in a story-like way.

These interactions were recorded on video using GoPro HERO3[1] cameras. To avoid occlusion, we recorded

The study was recorded by two cameras.

[1]https://www.gopro.com/

the interactions from two angles. The use of a Vicon[2] 3D motion capture system was considered but ultimately declined, because this system needs little spherical reflective markers on the tracked objects. These markers would significantly change the affordances of the tracked object, because they would limit the areas where these objects could be conveniently grasped.

Users were asked to fill out a questionnaire.

Additionally the users were asked to fill out a questionnaire after each scenario to find out if the tasks were realistic and to get general feedback on the concept of repurposing everyday objects as controllers. An excerpt of the questionnaire can be found in the appendix on page 49. The same questions were asked similarly for all three scenarios, the final questions were handed out after the participant had completed all three scenarios.

4.3 Study Scenarios

4.3.1 Office

A stapler, a coffee mug and a hole-punch are used.

In this scenario we imagine an office room. Three objects were chosen for the interactions in this scenario: a stapler, a coffee mug and a hole-punch. They are pictured in Figure A.4 in the appendix. The room should also have ceiling lights with a light switch next to the door, and an air conditioning system that is also controlled by a panel next to the door. These additional objects were present: two tables and a chair, a computer with keyboard and mouse, a landline telephone, a stack of papers and a ball-point pen. Since the repurposing actions should resemble the interactions with the original interfaces, we tried to find fitting tasks for each object:

The stapler can be pushed and thus slightly resembles a push-button, so the chosen repurposing task was to switch on the lights. The coffee mug is round and can be rotated, it resembles a rotary control, so users were asked to turn up the heat of the air conditioning by rotating the mug.

[2] http://www.vicon.com/System/Bonita

	normal use	repurposed use
stapler	staple papers	switch on lights
coffee mug	drink from it	control the air conditioning
hole-punch	punch holes	take or hang up a call

Table 4.1: Office: Objects and Actions

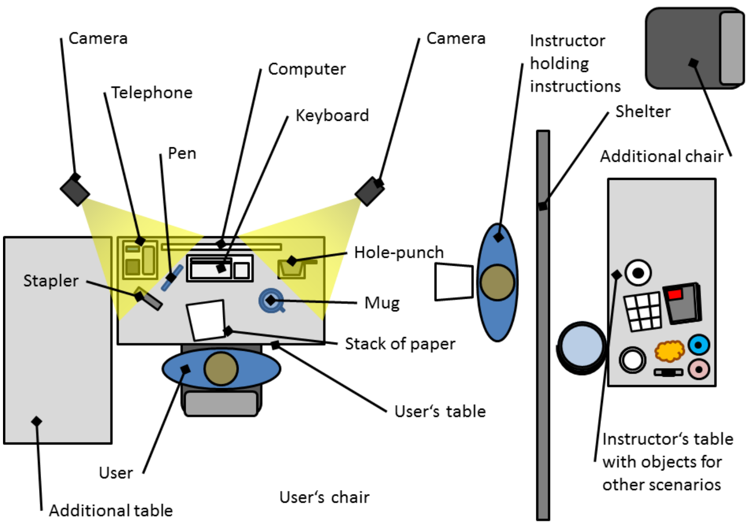

Figure 4.2: Preliminary Study: Setup of the "office" scenario.

Since you also push the hole-punch, we used it to simulate a shortcut to the speaker button on the telephone to quickly take or hang up a call.

The arrangement of the objects and the setup of the scenario is outlined in Figure 4.2.

4.3.2 Living Room

The objects selected for the interactions in this scenario were: a water bottle, a drinking glass, and a ball-point pen with a push mechanism. The used objects are pictured in Figure A.5 in the appendix. The living room imagined for

A water bottle, a drinking glass, and a ball-point pen were selected.

this scenario should also contain a chair, two tables, a TV with recording capabilities, a radio, a mobile phone, a TV guide, and a sudoku puzzle.

	normal use	repurposed use
water bottle	refilling the drinking vessel	change the volume of the TV/forward a recorded TV show
drinking glass	drink from it	change the volume of the radio
ball-point pen	fill out the sudoku puzzle	buzz open the door

Table 4.2: Living Room: Objects and Actions

Besides the normal use, the water bottle was repurposed to control the volume of TV by rotating, since volume controls are traditionally rotary knobs. We also used it to forward a recorded TV show by sliding the bottle on the table like the virtual slider known from video players on computers. This was done to find out if users preferred one repurposing action over the other, and if multiple commands bound to the same object would have an impact on the user experience. The drinking glass was used to control the volume of the radio by rotating. The users were asked to use the clicker of the pen to buzz the front door open.

The layout of the scenario is outlined in Figure 4.3.

4.3.3 Bath

The objects used for repurposing are a round bubble bath bottle, a shower gel with a pop-up cap, and a round creme can.

We expected the convenience aspect of repurposing everyday objects as Instant UIs to be the most prominent for this scenario, since getting out of the warm water in a bath tub can be really uncomfortable. A quite luxurious batroom is imagined to be able to control more devices. In this extravagant bathroom, a bathtub is present as well as a wall-mounted TV with an integrated DVD-player, dimmable ceiling lights and a ventilation system.

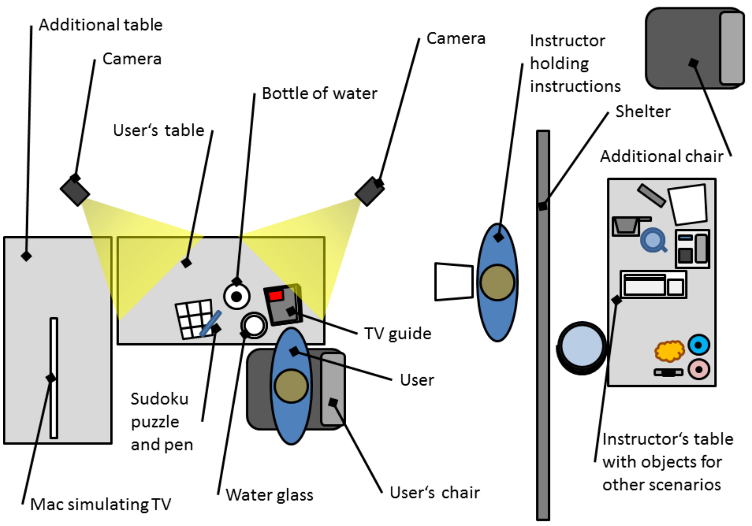

Figure 4.3: Preliminary Study: Setup of the "living room" scenario.

In this scenario, we selected the following objects: a round bubble bath bottle, a shower gel with a pop-up cap, and a round creme can. They are pictured in the appendix in Figure A.6.

To make this scenario more relaistic, we let the users wet their hands in a bucket of water. This should simulate the special requirements for controller devices while taking a bath.

	normal use	repurposed use
bubble bath bottle	screw off cap	change the volume of the TV
shower gel	pop open	start/stop the ventilation
creme can	screw off lid	dim the lights

Table 4.3: Bath: Objects and Actions

Users were asked to control the volume of a TV by rotation of the bubble bath bottle. The shower gel was popped open or close to start or stop the ventilation. This should simu-

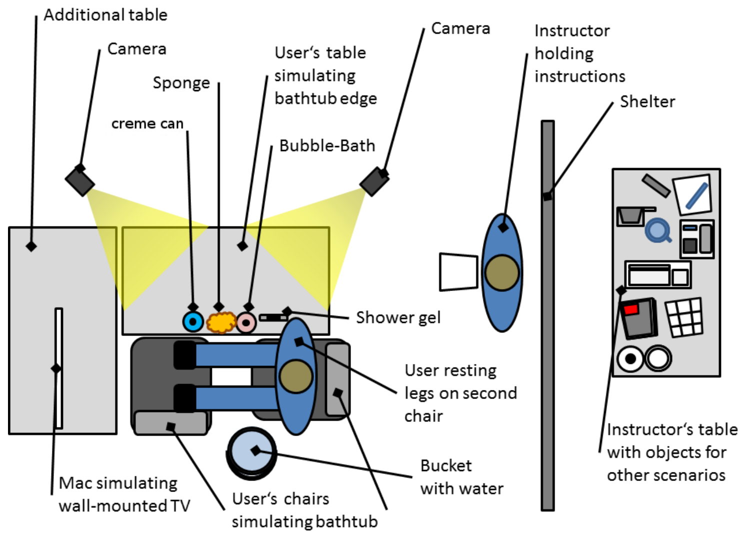

Figure 4.4: Preliminary Study: Setup of the "taking a bath" scenario.

late the flick of a switch. The round creme-can should be rotated to dim the lights, since dimmer switches are mostly rotary controls.

The the setup of the scenario including the positions of the objects is outlined in Figure 4.4. You can see that the bathtub was simulated by a second chair, where the users could rest their legs.

4.4 Evaluation

The study was conducted with eight participants aged 20 to 33 (M = 26.5, SD = 4.56). Two participants were female, two were left-handed. For some objects, we were able to identify certain trends and back up our assumptions about the way some objects are repurposed.

Generally we could identify a group of objects, that are normally handled with two hands, which are containers that can be opened. Since a certain amount of force is needed to screw or pop the container open, the second hand is used to hold the container in place. This applies to the water bottle, the creme-can and the bubble-bath bottle from our scenarios, where every user used both hands. In contrast, only one out of the repurposing interactions with these objects (which were rotating or sliding) was conducted using both hands. While this seems to be a very clear distinction, the problem arises that these touches usually do not happen simultaneously. In order to derive the user's intention, the system using this property to distinguish between normal and repurposed use would have to wait if a second hand is used or not, which reduces the value of this distinction.

Good distinction: objects that are opened with two hands, but repurposed with only one hand. Downside: touches do not happen simultaneously.

The next object identified with a relatively clear distinction is the drinking glass. All users grab the glass from the side to drink from it, while seven out of eight users grab the rim of the glass from the top to rotate it. This seems to be the best result, since the contact points can be relatively easily separated.

All users grab the drinking glass from the side to drink, and almost all grab it from the top to rotate it.

These distinctions are not as clear when we look at the other drinking vessel, the coffee mug. It has an additional feature, the handle on the side, which offers an extra affordance (grab the handle). The interaction for the mug is more spread out: still the majority (six out of eight) grabs the rim from the top to rotate the mug, but the remaining two users use the handle to push or drag the mug in a circular motion. Normal use is impacted even more, with four users using the handle to drink from the cup while the other four users directly grab the body of the mug and ignore the handle. While these normal interactions are all coming from the side, the patterns of the touch points are relatively different compared to the touch points of the drinking glass. Especially the overlapping contacts on the handle could create ambiguities when trying to differentiate between normal and repurposed use.

Coffee mug: handle interferes and spreads out contact points.

Another interesting aspect was the use of the stapler. While we initially expected all users to use the full hand for normal stapling to apply greater force, and only one finger to simulate a push-button, we were surprised to find out that the majority of users (six out of eight) used the stapler in mid-air for stapling. Additionally, almost all users

Stapler used mid-air to staple, push-button use not as subtle as expected.

(seven out of eight) performed the push-button gesture on the table with the full hand, two of them even pushing hard enough to waste a staple.

Hole-punch almost used identically.

The results for the hole-punch were almost identical when only looking at the pushing and hole-punching gesture. The only difference observed here was the location of the action: for the normal use, almost all (seven out of eight) users fetched the hole-punch beforehand and positioned it in front of them. To simulate a push-button, all users simply reached to the side and pushed the hole-punch there.

The shower gel is hard to open, blurs out potential differences.

The shower gel was also used quite similarly. All users grabbed the bottle and opened it with two hands mid-air for the normal use. When asked to repurpose it by only popping open the pop-cap, only two users managed to do it with only one hand. Three of the remaining six users tried to do it, but had to use the second hand because they struggled with the relatively firmly closed cap. Five out of eight users repurposed the shower gel without lifting it in the air. But because the overall interactions were relatively fuzzy because of the tightly closed cap, the patterns of touches did not seem to have any observable differences.

Users play around with the pen.

The ballpoint pen with a push-button presented itself as the least usable of all objects. Three users grab the pen and fiddle with it throughout the experiment. This absent-minded play greatly interferes with the repurposed use, which is just clicking. Even the normal use varied greatly, where three users used different hands to push the writing tip out and back in. Three users did not even push tip back in after finishing writing with it.

Users initially found the idea of repurposed objects as controllers strange but quickly adapted to it.

In the survey all people commented, that the idea to control something with an everyday object seemed weird to them, but that they got used to it after a while. The selection of objects was consistently perceived as fitting to the respective scenario, whereas some users missed some connections between the everyday object and the controlled device. The rotation gestures to increase and decrease volume were generally seen as fitting. Five of the eight users remarked that it would be difficult to distinguish between normal and repurposed use, one user additionally mentioned that it would be difficult to remember the mapping of the everyday objects to the controlled devices. Most users (six out of eight) did not like the idea of leaving the shower gel bottle open after repurposing it.

We also made some more general observations. Some objects seem to have a preferred side of interaction: the stapler and the hole-punch are mostly used with the left hand, because staples and holes are on the left side of the paper by convention. Complex actions are more likely executed with the dominant hand: writing was always done with the dominant hand whereas repurposed use is usually simpler than normal use and was predominantly done with the hand closer to the object.

Some objects have a preferred side of interaction. Complex actions are more likely executed with the dominant hand.

4.5 Takeaways

The results from this study illustrate the difficulties of an implicit approach to discriminate between normal and repurposed use of everyday objects. The priorities of affordances are always dependent on the individual user, such that a clear distinction between used and unused affordances is not possible. For example, while some users prefer to grab a coffee mug at the handle, others ignore this affordance and directly grab the body of the mug.

Users rank affordances differently.

For our further research, we will focus on the most promising objects and work towards possible technical solutions. We will try to reinforce and refine the distinctive properties with respect to a possible technical solution.

Chapter 5

Focus Study on Promising Objects

With these results of the preliminary study in mind we started to design the follow-up study. We chose the most promising objects as the focus upon which we wanted to conduct further research. This was done to consolidate the findings and create more precise attributes upon which a system could rely for distinction. The drinking glass, the water bottle, the stapler and the coffee mug were taken over from the preliminary study.

Focus on most promising objects.

5.1 Research Questions

We concentrated on the initial touch points of the interactions. This approach avoids delay in the recognition process, which would be inherent to an approach using gesture sequences.

Our new research questions are

- Are the initial contact points for normal or repurposed use the same for all users?

- If not, are the initial contact points consistent per individual user?

5.2 Design

We extract the touches points manually from video.

We designed the next study with this new goal in mind. Different methods were tried out to record the actual touch points, in the end the manual extraction from a video fulfilled our requirements best. With this approach, the users were not influenced by additional devices or changed affordances of the objects. To increase precision and avoid occlusion three additional cameras were added (compare Figure 5.1). They provided close-up detail views and a bird's eye overview.

Office and living room scenario were kept, but the tasks had to be performed multiple times.

The scenarios from the preliminary study were generally kept, but simplified, and the story-aspect was much reduced. This was done because the tasks should be performed several times by the participants to check if interactions are consistent per user. The living room scenario (compare Figure 5.2) was adapted to replace the chair with a comfortable couch and the side table with a low living-room table. The taking a bath scenario (compare Figure 5.3) was completely removed, because it was too particular and offered too little variety of objects for interaction.

Like in the previous study, the drinking glass, the water bottle, and the coffee mug were rotated for their repurposed use. The stapler was still used as a push-button for its repurposed use.

5.3 Conduction of the Study

The study was conducted with 14 users aged 22 to 33 (M = 25.36, SD = 2.87), five of which were female. The tasks were simplified versions of the tasks of the preliminary study, for example: "Please rotate the bottle of water to increase the volume of the TV."

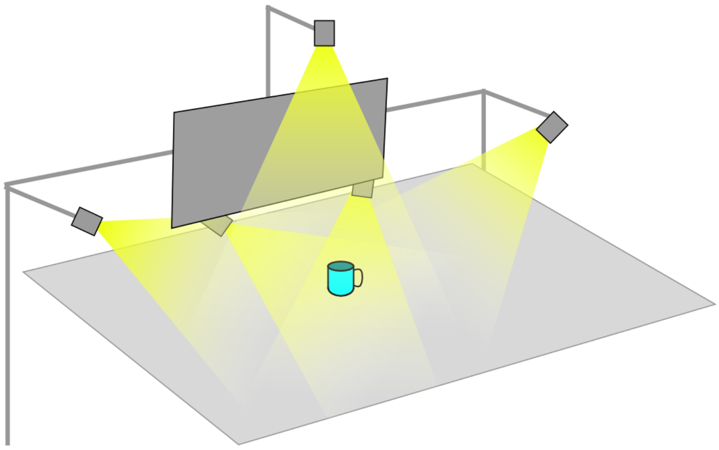

Figure 5.1: Focus Study: The extended camera setup for the main study. A camera for a bird's eye view was added as well as two cameras for close-up touch point recording.

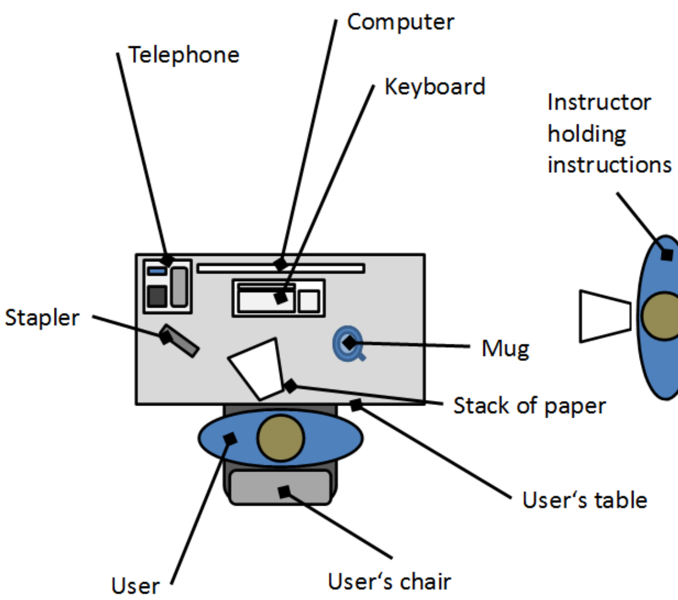

Figure 5.2: The simplified office scenario for the focus study.

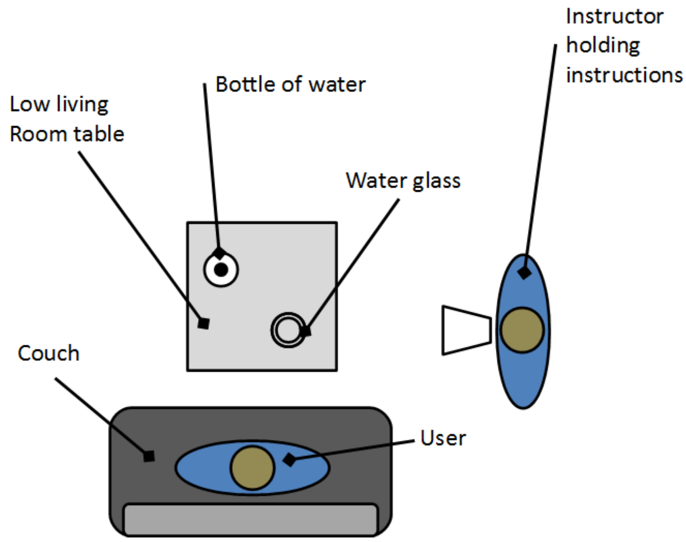

Figure 5.3: The altered living room scenario for the focus study.

5.4 Evaluation

After manually extracting the contact points for each interaction from the videos, we created heatmaps for each object showing the regions where touch interaction took place. These graphical representations help to get a better visual understanding of the results.

5.4.1 Object Heatmaps

Heatmaps show relative concentration of touch points.

Touches are represented by circles filled with a radial gradient. The colors indicate the number of touches in area, with the highest number of touches on one point normalized to the maximum of the color gradient pictured in Figure 5.4. Areas without any touches remain white, while the areas with the most touches are displayed in red.

The code used to create these heatmaps is based on

Figure 5.4: The Heatmaps were generated with this color gradient.

a processing[1] sketch presented in an article by Philipp Seifried: Generating heatmaps from code[2].

Coffee Mug

Contact points for normal use on handle and body.

The interactions for the normal use of the coffee mug resemble those observed in the preliminary study. Again, all users approached the mug from the side to drink from it. They used either the handle (nine users) or directly grabbed the body of the mug (five users). The percentages differ a little from the original 50% from the preliminary study, still no completely different interaction was observed.

Contact points for repurposed use mostly on rim, but also handle and body.

When we have a look at the repurposed use, which was rotating, the distinction just by looking at the contact points gets more difficult (Compare Figure 5.5). Though the majority (nine users) still grabbed the upper rim to rotate the cup, three users touched the handle (two from above, one from the side) and two even directly grabbed the body of the mug. The touches on the handle and especially the direct touch on the body of the mug are indistinguishable from the patterns observed from the normal use. If only the initial contact points were used, around one in three commands would not be recognized but interpreted as normal use.

Drinking Glass

The drinking glass is the most basic item, still only 79% of the users use the rim to rotate it.

Based on the results of the preliminary study, the drinking glass had the prospect of showing the most distinct

[1]https://www.processing.org/

[2]http://philippseifried.com/blog/2011/09/30/generating-heatmaps-from-code/

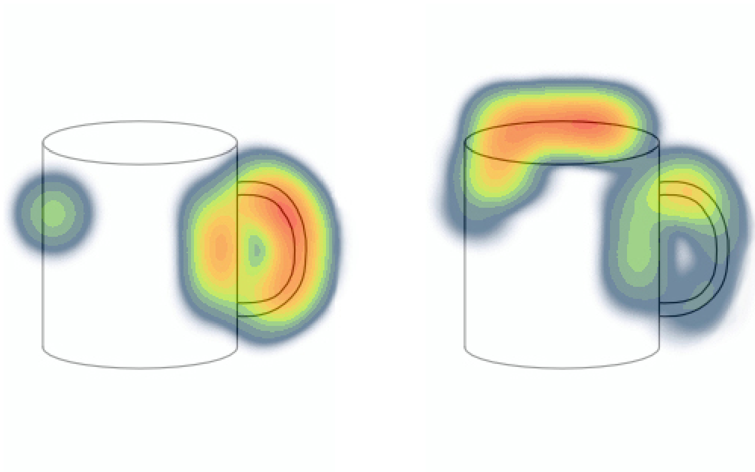

Figure 5.5: Heatmaps of the different uses of a coffee. Left: normal use (drinking). Right: repurposed use (rotating).

touch patterns. Though again all users grab the glass from the side to drink, the rotation is not consistent even without a diverting handle (Compare Figure 5.6). Three users grabbed the glass from the side to to rotate, making the exact same gesture as used when drinking. Distinguishing the uses based only on initial touches would result in about one in five missed commands.

Water bottle

Although it is the biggest item, touches happen in very similar places.

As the water bottle has the largest touchable surface of the tested objects, we expected the largest variance within each way of use. This assumption was confirmed, looking at Figure 5.7 it can easily be seen that the area covered by the touches is relatively big. For the normal use the initial contact points mass at the center of the bottle. The design of the bottle intensifies this through the bulge, which provides a better grip on the smooth glass surface. Since we are only interested in the initial touch, the fact that all people used both hands to open the bottle does not help here. Still the resulting heatmaps look very similar and cover almost exactly the same areas. One user even picked up the bottle at the cap.

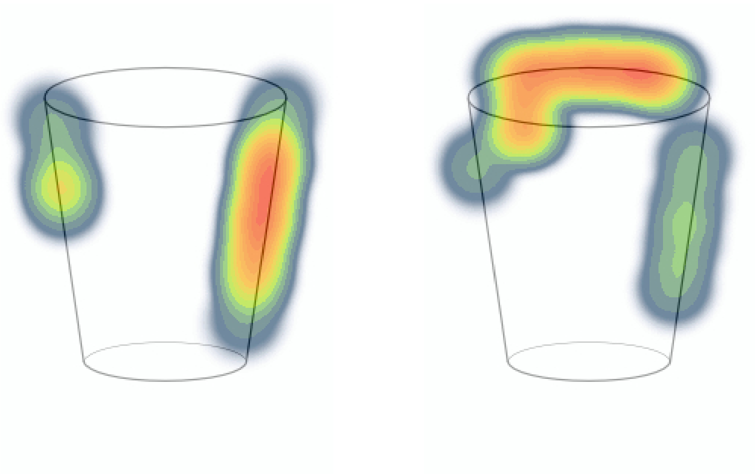

Figure 5.6: Heatmaps of the different uses of a drinking glass. Left: normal use (pick up to drink). Right: repurposed use (rotating).

The repurposed use shifted the focus a little away from the middle bulge towards the cap at the top. Four users only touched the cap to rotate the bottle, five used the bottle neck and four the bulge in the middle. Within the individual repetitions, touch areas slightly shifted from neck to middle and vice versa.

Normal and repurposed use share almost identical areas of touches.

Without clear distinctions even for individual users, the bottle is least suitable of the objects to reliably predict the intention of the user based on initial touch points alone.

Stapler

Since the result of the previous study seemed surprising this interaction was mainly kept to validate the previous results. Though not 75% of the users performed normal stapling mid-air like in the preliminary study, still five out of 14 performed this way of interaction. The initial contact points were very difficult to locate, since these users picked up the stapler and immediately migrated into a clutch grip (compare Figure 5.8).

36% of the users utilized the stapler mid-air for the normal use.

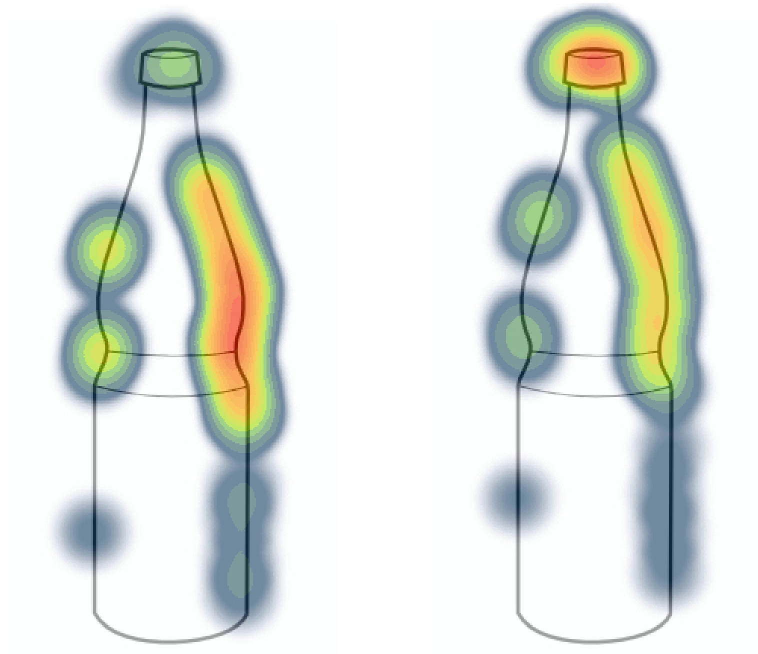

Figure 5.7: Heatmaps of the different uses of a water bottle. Left: normal use (pick up to open). Right: repurposed use (rotating).

The repurposed use however took place on the table for all users, this time with an even 50% using the full hand and the other 50% using only one or two fingers to simulate a push-button click. However, the contact areas for stapling when performed on the table and repurposing the stapler as a push button with the full hand were indistinguishable. In contrast to the preliminary study, no user pushed hard enough to waste a staple this time.

Making destinctions based only on initial contact points would produce many errors.

To summarize, our envisioned approach of a robust system, that is able to discriminate between normal and repurposed use solely based on initial contact points, seems unrealistic. Even for the object with the most differing areas of contact points, such a system would still produce errors about 20% of the time. To create a reliable system to implicitly derive the user's intention from the interaction alone, other methods have to be considered. Some alternatives are presented in the next chapter.

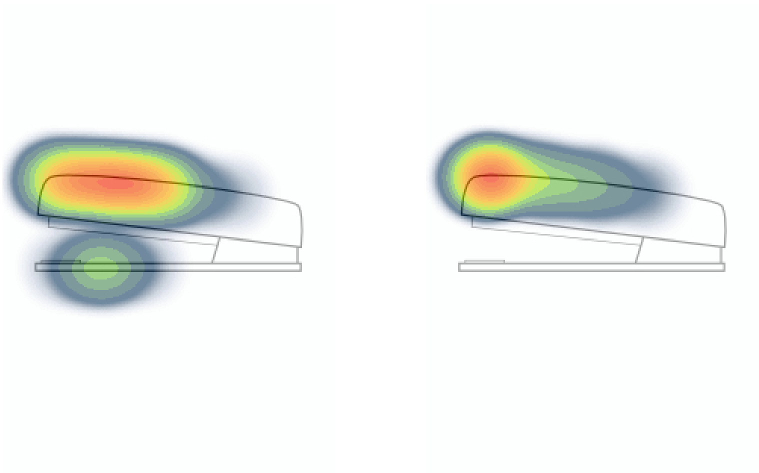

Figure 5.8: Heatmaps of the different uses of a stapler. Left: normal use (staple paper). Right: repurposed use (push-button).

Chapter 6

Summary and Future Work

We tried to find discerning factors to implicitly derive the user's intention when using everyday objects. This would help to eliminate the need for explicit mode switches to discriminate between normal use of everyday objects and their repurposed use as tangible controllers.

We decided to base our approach in the initial contact points on the objects, so our user studies focused on these touches. To prevent influences on the affordances of objects by certain method of measurement, we chose to only record the interactions on video.

6.1 Summary and Contributions

Unfortunately, we could not find any object without ambiguous touch areas. When only considering contact points, a distinction was only reliably possible for the most basic object, the drinking glass, with still about 20% errors.

However, we still found out some characteristics for everyday objects which are better suited to be repurposed. These characteristics could be utilized when designing new systems that repurpose everyday objects as controllers.

We infered the following design implications from our research:

- Simpler objects work better. The more additional features exist, the more ways of interaction are possible and will eventually be used.
- Pens do not work. People are used to occupy their hands with something to toy around with, and pens are really predestined for that. Avoid other small fiddly objects.
- Find adequate metaphors by looking at the exploited affordances of interactions. The more a repurposed interaction resembles the original interaction, the more convenient it is for the user.
- Complex gestures tend to be performed with the dominant hand. Simpler gestures, like lots of the repurposed interactions
- Repurpose objects with affordances that can easily be used without much effort. If a rotary control gets stuck often, or needs much force to be rotated, the interactions would be impaired.
- Avoid often used objects. Even with a system with very low error rates, the absolute number of errors would still be inconvenient.

6.2 Future Work

An interesting approach to follow up on this thesis would be to focus on one object (for example the water glass) and try to prototype it as a touch-aware object. Maybe some technology like FlexAura [Liu and Guimbretière, 2012] could be incorporated to enhancing surface touch detection and even hovering. With more detailed information the gestures could possibly be distinguished much better.

Since our research only looked at the normal and repurposed use of everyday objects it could be interesting to look at other actions that are performed regularly with everyday objects. Repositioning comes to mind, where objects are simply moved around or out of the way. This could greatly interfere with the detection of repurposed use.

To enhance the prediction other methods of capturing the interaction with everyday objects could be employed. If it would be possible to unintrusively track the fingers or even hand postures of the user, a much better prediction can be imagined. Such systems would allow to look at the interaction sequence leading up to the initial contact with the object, where differences could already be visible.

Appendix A

Appendix to the Preliminary Study

These are the results from the questionnaire, which was handed out at the preliminary study.

	Office	Living Room	Bath
Were the tasks in this scenario realistic?	M=4.38, SD=0.48	M=4.63, SD=0.48	M=3.88, SD=0.78
Were the objects presented typical for this scenario?	M=4.38, SD=0.48	M=4.50, SD=0.50	M=4.38, SD=0.70
Were the objects suitable for their appropriated task?	M=3.38, SD=1.41	M=3.63, SD=1.11	M=3.38, SD=0.86
Did it feel natural to repurpose items?	M=2.50, SD=0.87	M=3.50, SD=0.87	M=3.13, SD=0.60

Table A.1: Data from the Questionnaire.

A likert-scale was used with 1 representing strong disagreement and 5 representing strong agreement.

M is short for median, SD is short for standard deviation.

Informed Consent Form

Evaluating

PRINCIPAL INVESTIGATOR Christian Humme
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Email: christian.humme@rwth-aachen.de

Purpose of the study: The goal of this study is to understand how everyday objects are being repurposed and if the proposed scenarios are realistic. Participants will be asked to handle everyday objects in their intended way and repurposed as controllers. Interaction with the objects and their movement will be recorded.

Procedure: Participation in this study will involves three phases. In each phase a scenario with corresponding objects will be presented to the user. The investigator will then present a story with concrete tasks for the user to interact with one of these objects. This study should take about 45 minutes to complete.

After the study, we will ask you to fill out the questionnaire about the tested system. In this questionnaire, we will ask for some general demographic data and questions about the user experience in the scenarios.

Risks/Discomfort: You may become fatigued during the course of your participation in the study. You will be given several opportunities to rest, and additional breaks are also possible. There are no other risks associated with participation in the study. Should completion of either the task or the questionnaire become distressing to you, it will be terminated immediately.

Benefits: The results of this study will be useful to create systems that allow objects to be used as alternative input devices.

Alternatives to Participation: Participation in this study is voluntary. You are free to withdraw or discontinue the participation.

Cost and Compensation: Participation in this study will involve no cost to you. There will be snacks and drinks for you during and after the participation.

Confidentiality: All information collected during the study period will be kept strictly confidential. You will be identified through identification numbers. No publications or reports from this project will include identifying information on any participant. If you agree to join this study, please sign your name below.

_____ I have read and understood the information on this form.
_____ I have had the information on this form explained to me.

Participant's Name	Participant's Signature	Date
	Principal Investigator	Date

If you have any questions regarding this study, please contact Christian Humme at +49(160)3529600, email: christian.humme@rwth-aachen.de

Figure A.1: Example of the Informed Consent Form each participant of the user studies had to sign.

Office Scenario:

1. Were the tasks in this scenario realistic?

☐ very unrealistic	☐ unrealistic	☐ decent	☐ realistic	☐ very realistic

If not, please explain which ones were unrealistic and why:

2. Were the objects presented typical for the scenario?

☐ very untypical	☐ untypical	☐ decent	☐ typical	☐ very typical

If not, please explain which ones were untypical and why:

3. Were the objects suitable for their appropriated task?

☐ very unsuitable	☐ unsuitable	☐ neutral	☐ suitable	☐ very suitable

If not, please explain which ones were unsuitable and why:

4. Did it feel natural to repurpose items?

☐ very strange	☐ strange	☐ neutral	☐ natural	☐ very natural

If not, please explain why:

Figure A.2: Excerpt concerning the office scenario from the questionnaire handed out to the participant after each scenario.

Final Questions:

1. Do you think you manipulated the objects in the same way when using them normally and repurposing them as tangible controllers?

☐	☐	☐	☐	☐
very differently	differently	more or less the same	similar	very similar

If you used them differently, please explain when this occurred to you and if you did it on purpose:

2. Do you have any further comments?

Figure A.3: Excerpt including the final questions of the questionnaire handed out to the participant at the end of the user study.

Figure A.4: These objects were used in the office scenario.

Figure A.5: These objects were used in the living room scenario.

Figure A.6: These objects were used in the bath scenario.

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Typeset October 27, 2014