

An analysis of the  
conflict between  
the user control  
and the need for  
physical-visual  
consistency in  
tangible tabletop  
interaction

Diploma Thesis at the  
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*Aachen, Aug, 2011*  
*Ronny Seidel*



# Contents

<b>Abstract</b>	<b>xv</b>
<b>Überblick</b>	<b>xvii</b>
<b>Acknowledgements</b>	<b>xix</b>
<b>Conventions</b>	<b>xxi</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Thesis Context . . . . .	1
1.2 Thesis Motivation . . . . .	4
1.3 Thesis Structure . . . . .	4
<b>2 Related Work</b>	<b>7</b>
2.1 Review Characteristics . . . . .	7
2.2 Literature Collection . . . . .	9
2.2.1 Actuated Workbench . . . . .	10
2.2.2 Augmented Coliseum . . . . .	11
2.2.3 Remote Active Tangible Interactions .	13

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2.2.4	Mechanical Constraints . . . . .	14
2.2.5	Madgets . . . . .	15
2.2.6	Tangible Bots . . . . .	17
2.3	Consequences for Thesis . . . . .	18
<b>3</b>	<b>Initial Study</b>	<b>23</b>
3.1	Motivation . . . . .	24
3.2	Control in Psychological Literature . . . . .	24
	Conclusion . . . . .	26
3.3	Brainstorming . . . . .	28
3.3.1	Procedure . . . . .	28
3.3.2	Results . . . . .	30
3.3.3	Discussion . . . . .	33
3.4	Consequences for Main Study . . . . .	35
<b>4</b>	<b>System Design</b>	<b>39</b>
4.1	Tabletop System . . . . .	39
4.1.1	Hardware . . . . .	40
4.1.2	Tangibles . . . . .	41
4.1.3	Software Development . . . . .	42
4.2	Modifications . . . . .	44
4.2.1	Tracking with Vicon . . . . .	44
4.2.2	Tangibles . . . . .	46

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4.2.3	Tracking Method . . . . .	47
4.2.4	Actuation Algorithm . . . . .	48
4.3	Implementations . . . . .	50
4.3.1	Magnet Array Interface . . . . .	51
	Usage . . . . .	51
4.3.2	User Test Design . . . . .	54
	Task Description . . . . .	54
	Task User Interface . . . . .	55
	Test Control . . . . .	58
4.3.3	Wizard of Oz . . . . .	59
	Usage . . . . .	60
<b>5</b>	<b>User Study</b>	<b>63</b>
5.1	Format . . . . .	63
5.1.1	Experiments . . . . .	63
5.1.2	Data Collection Techniques . . . . .	64
5.1.3	Test Environment . . . . .	64
5.2	Challenges . . . . .	65
5.2.1	Awareness of Test Situation . . . . .	65
5.2.2	Awareness of Wizard of Oz . . . . .	66
5.3	Setup . . . . .	67
5.3.1	Environment . . . . .	67
5.3.2	Participants . . . . .	68

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5.3.3	Test Procedure . . . . .	69
5.3.4	Preparation of User . . . . .	70
5.4	Hypothesis . . . . .	71
5.5	Results . . . . .	72
5.5.1	Preparation . . . . .	72
5.5.2	Video Observations . . . . .	72
5.5.3	Speaking Aloud . . . . .	78
5.5.4	Retrospective Interviews . . . . .	80
5.5.5	Questionnaires . . . . .	82
5.6	Conclusion . . . . .	86
5.6.1	Hypothesis <i>H1</i> . . . . .	86
5.6.2	Hypothesis <i>H2</i> . . . . .	87
5.6.3	Significant Observations . . . . .	88
<b>6</b>	<b>Summary and Future Work</b>	<b>89</b>
6.1	Summary and Contributions . . . . .	89
6.2	Future Work . . . . .	92
<b>A</b>	<b>Declaration of consent</b>	<b>95</b>
<b>B</b>	<b>Questionnaire</b>	<b>97</b>
	<b>Bibliography</b>	<b>103</b>
	<b>Index</b>	<b>107</b>



# List of Figures

1.1	The ReacTable . . . . .	2
1.2	Music instrument with Tangible Bots . . . . .	3
2.1	The Actuated Workbench . . . . .	10
2.2	The Augmented Coliseum . . . . .	12
2.3	Remote Active Tangible Interactions . . . . .	13
2.4	Mechanical constraints . . . . .	14
2.5	The Madgets tabletop . . . . .	16
2.6	Tangible Bots . . . . .	17
4.1	Madgets tabletop structure . . . . .	40
4.2	Gradient marker . . . . .	41
4.3	Madgets . . . . .	42
4.4	Madgets software system . . . . .	43
4.5	reactIVision . . . . .	45
4.6	Vicon tracking system . . . . .	45
4.7	Tangibles . . . . .	47

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4.8	Puck tracking . . . . .	49
4.9	Puck motion . . . . .	50
4.10	Magnet array controller GUI . . . . .	51
4.11	Calibration software . . . . .	53
4.12	Mouse gestures . . . . .	53
4.13	Magnets view on tabletop . . . . .	54
4.14	Task design overview . . . . .	55
4.15	Puck is moved . . . . .	56
4.16	Tangible switch . . . . .	56
4.17	Target order information . . . . .	57
4.18	Puck placement crosses . . . . .	57
4.19	Visual support methods . . . . .	58
4.20	User task controller window . . . . .	59
4.21	Next phase panel . . . . .	59
4.22	Extended magnets view . . . . .	61
5.1	The user test environment . . . . .	68
5.2	Pinning a puck to the surface . . . . .	73
5.3	Pushing a puck in an anticipated direction . . . . .	73
5.4	Withdrawal of the hand gesture . . . . .	74
5.5	Offer resistance by pushing puck in opposite movement direction . . . . .	75
5.6	Avoid collision by pushing puck aside movement path . . . . .	76

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5.7	Leading a puck along the movement path . .	77
5.8	Actuation experience ratings . . . . .	82
5.9	Visual support ratings . . . . .	83
A.1	Declaration of Consent . . . . .	96
B.1	Questionnaire part 1 . . . . .	98
B.2	Questionnaire part 2 . . . . .	99
B.3	Questionnaire part 3 . . . . .	100
B.4	Questionnaire part 4 . . . . .	101



## List of Tables

3.1	Irrelevant statements . . . . .	30
3.2	Statements regarding interference . . . . .	31
3.3	Statements regarding information . . . . .	31
3.4	Statements regarding emotions . . . . .	32
3.5	Statements regarding coordination . . . . .	32
3.6	Statements regarding benefits . . . . .	33
3.7	Context-dependent meaning of predictability	34
3.8	Context-dependent meaning of explainability	35
3.9	Context-dependent meaning of influence . .	35
5.1	User test procedure . . . . .	69
5.2	User test situations . . . . .	70
5.3	Summary of observed behavior from video recordings . . . . .	78
5.4	Overview of the findings from the comments while executing the task . . . . .	79
5.5	Overview of the findings from the retrospec- tive interviews . . . . .	82



# Abstract

Tangible user interfaces (TUIs) on an interactive tabletop are physical controls that can be operated by a user in order to change digital information displayed on the tabletop display. The tabletop system's inability to update physical characteristics of tangibles, e.g., the location on the surface, leads to inconsistency between the digital and physical world. To guarantee that consistency, actuated TUIs have been developed. Such user interfaces are physical controls that can be forced to change their location or even the state of its agile subparts, e.g., rotating a knob. Especially working environments benefit from that concept in which spatially separated users sharing tangible resources on tabletops. However, a user has occasionally only partial control and may feel a loss of control over the physical environment. Although the usage of actuation technology has increased in recent years, few projects contribute to the question how users experience the reduced control.

This thesis addresses the problem of reduced control and evaluates techniques to minimize the loss of control. A initial study uses theories from psychology on user control and concludes by means of a brainstorming session corresponding techniques to minimize the loss of control. A qualitative study finally evaluates the proposed techniques. Furthermore the study provides insight into the emotional state of the user while interacting with actuated tangibles. For collecting data we asked participants to place a set of shared pucks in a particular order in coordination with a spatially separated communication partner. From analyzing video recordings, retrospective interviews, questionnaires and comments we concluded that providing adequate visual support and actuation interference support will decrease the loss of control when interacting with actuated TUIs.





# Überblick

Greifbare Benutzerschnittstellen auf einem interaktivem Tisch sind physische Steuerelemente, die von einem Benutzer bedient werden können, um digitale Information auf der Tischbildfläche zu verändern. Derartige Systeme sind nicht in der Lage die physikalischen Eigenschaften dieser greifbaren Steuerelementen, beispielsweise die Position auf der Oberfläche, zu aktualisieren. Somit kann die Konsistenz zwischen der digitalen und der physischen Welt nicht mehr garantiert werden. Damit dies gewährleistet werden kann, wurden steuerbare, greifbare Benutzerschnittstellen entwickelt. Derartige Benutzerschnittstellen sind physische Steuerelemente, die ihre Position auf der Tischoberfläche oder sogar ihre bewegliche Bestandteile ändern können. Von diesem Konzept profitieren besonders räumlich von einander getrennte Anwender, die sich greifbare Steuerelemente auf interaktiven Tischen teilen. Allerdings hat ein Benutzer durch die gemeinsame Nutzung nur beschränkt die Kontrolle über die Steuerelemente und kann einen Kontrollverlust hinsichtlich der physischen Umgebung empfinden. Obwohl sich die Verwendung von steuerbarer Technologie in den letzten Jahren vermehrt hat, beschäftigen sich bis her nur sehr wenige Projekte mit der Frage, wie die Benutzer diesen Kontrollverlust empfinden.

Diese These behandelt das Problem des Kontrollverlustes und evaluiert entwickelte Techniken, in der Hoffnung das Empfinden des Kontrollverlustes zu minimieren. Eine erste Studie verwendet Theorien aus der Psychologie bzgl. des Kontrollbegriffes. Mit Hilfe eines Brainstormings werden diesbezüglich Techniken festgelegt, die den Kontrollverlust minimieren sollen. Später wertet eine qualitative Studie die vorgeschlagenen Techniken aus und gibt darüber hinaus einen Einblick in die Gefühlslage des Benutzers, während dieser mit den steuerbaren, greifbaren Benutzerschnittstellen interagiert. Für die Ermittlung der Daten werden die Teilnehmer gebeten, greifbare Pucks in Zusammenarbeit mit einem entfernten Partner in einer bestimmten Reihenfolge zu sortieren. Die Analyse von Videoaufzeichnungen, retrospektiven Interviews und Befragungen ergab, dass die Bereitstellung einer adäquaten visuellen Unterstützung und einer Technik zur Beeinflussung der steuerbaren, greifbaren Benutzerschnittstellen, das Empfinden des Kontrollverlustes während der Interaktion verringert.



# Acknowledgements

I would like to thank everyone who supported me!



# Conventions

Throughout this thesis we use the following conventions.

## *Text conventions*

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

This thesis addresses the problem of reduced user control in the context of actuated tangible user interfaces (TUIs) on tabletops. To understand that problem this chapter introduces the topic, whereas the structure looks as follows:

**Section 1.1—“Thesis Context”** illustrates the characteristics of TUIs and actuated TUIs on tabletops by an example.

**Section 1.2—“Thesis Motivation”** emphasizes the problems with actuated TUIs on tabletops and points out the relevance of this thesis.

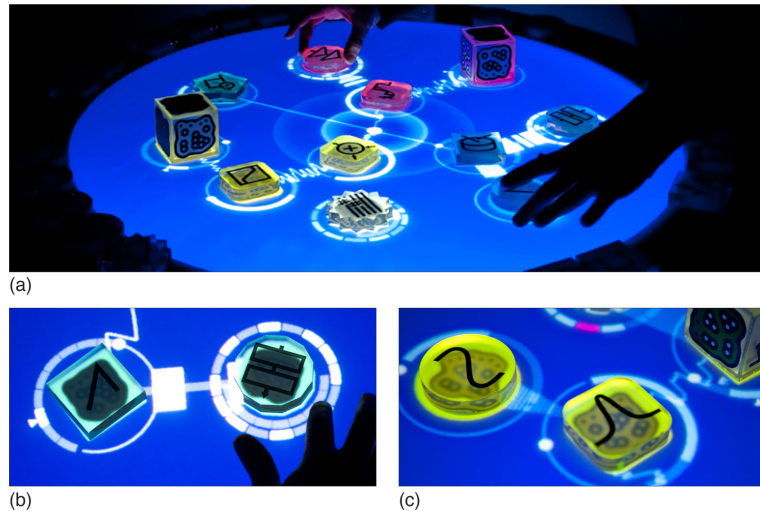
**Section 1.3—“Thesis Structure”** presents an overview of the thesis structure by briefly summarizing the different phases.

### 1.1 Thesis Context

The ReacTable is an electronic musical instrument developed by [Jordà et al., 2007]. The goal of the project was to turn music into something visible and tangible. Therefore, the research group constructed an interactive round tabletop on which physical pucks can be placed (figure 1.1.a). In this context, those pucks represent tangible building blocks

The ReacTable is a music instrument

of electronic music, each having a different functionality. Pucks either generate music or sound effects, process effects, or serve as controller.



**Figure 1.1:** The ReacTable. (a) Tabletop surface with several pucks. (b). Connected pucks. (c). The frequency puck. (All figures from [www.reactable.com](http://www.reactable.com)<sup>1</sup>)

Music is generated  
by manipulating  
physical pucks

Once a musician places a puck on the surface, a connection between neighboring pucks will be established (figure 1.1.b). The effect is an audible musical composition and the visualization of the connections on the tabletop surface. By turning a puck, adding a further puck, or changing the distance to other pucks, a musician is able to influence the audible and visual output. For example, a musician alters the number of repeated sound effects per time unit by turning the frequency puck (figure 1.1.c) in the corresponding direction.

Pucks make music  
tangible

The haptic nature of music and the instant feedback turns the tabletop into an intuitive and easy to use music instrument that can be operated on the fly. Unfortunately, the musical interface has a weak point and that is the passive nature of the pucks. No technique exists that prevents a musician from turning a puck below a minimum value respectively above a maximum value or hinders a musician from placing a puck on an invalid position on the surface. In other words, the reactTable is unable to pass on digital re-



restrictions or rules to the physical pucks. As a result, the consistency between the physical world and the digital counterpart cannot be guaranteed.

For instance, a musician rotates the frequency knob in order to modify the repetition rate of a specific sound effect. Assume an underlying software restricts the selectable frequency to a certain range. The physical nature of the pucks enables the musician to turn the puck beyond the frequency limits. The effect is that turning beyond the limit does not further influence the audible and visible output and the impression of unified input and output gets lost.

Interacting with a frequency puck

Motivated by the weakness of the passivity of physical pucks, [Pedersen and Hornbaek, 2011] developed an advanced electronic musical instrument (figure 1.2.a). Their construction is similar to the *reactTable*, except that the instrument is equipped with actuation technology [Poupyrev et al., 2007]. A puck is now motorized and capable of moving and rotating (figure 1.2.b). Hence, changes or restrictions in the digital representation can be passed to the physical counterpart.

Making music with motorized pucks

The frequency puck in the aforementioned interaction example can so be forced to rotate back after the musician turns the puck beyond the frequency limits. Hence the digital representation of the frequency puck and the pucks itself are kept consistent and the impression of unified input and output remains intact.

Interacting with a motorized frequency puck



**Figure 1.2:** Musical instrument with Tangible Bots. **(a)** The user interface of the musical instrument. **(b)** A Tangible Bot. (All figures from [Pedersen and Hornbaek, 2011])

## 1.2 Thesis Motivation

Reduced user control	The previous section introduced a tabletop system equipped with actuation technology, that is capable of forcing a physical object on the surface to change its location or orientation. The benefit is, that in this way consistency between the digital object and its physical counterpart can be guaranteed. On the other hand, a user has occasionally only partial control and may feel loss of control over the physical environment. The feeling could intensify if the actuated tangibles do not behave in the way desired or expected by the user.
Minimize loss of control	We argue that there is a need to minimize the loss of control. The question arises how to provide adequate mechanisms to balancing the users' desire to control and the need for actuating tangibles on tabletops. For that reason, we reviewed research literature and searched for studies and theories that contribute to our concern.
Review results are unsatisfying	Unfortunately, the review process yielded unsatisfying results. Although there is a growing interest in actuated TUIs on tabletop, few literature exists that somehow contributes to our concern. Either research groups explore the potentials of actuation technology [KOJIMA et al., 2006, Weiss et al., 2010, Pangaro, 2003, Gabriel et al., 2008] or conduct studies [Patten and Ishii, 2007, Pedersen and Hornbaek, 2011] to address effectiveness and efficiency issues by comparing active tangibles with other user interfaces. Very few projects [Richter et al., 2007] propose promising results. Therefore we concluded, that further research in this field of tangible tabletop interaction is necessary.

## 1.3 Thesis Structure

In order to follow the evolution of this work, the thesis is structured in the following chapters:

**Chapter 2—“Related Work”** offers an overview of literature published in the context of actuated tangibles on

tabletops and emphasizes why research needs to be carried out.

**Chapter 3—“Initial Study”** presents an context-dependent understanding of user control, and based on that proposes techniques for minimizing loss of control.

**Chapter 4—“System Design”** illustrates the tabletop system that we are using for a user study and describes the design of the user tasks.

**Chapter 5—“User Study”** explains how we conducted the user study and presents the observations from video recordings, comments, retrospective interviews and questionnaires.

**Chapter 6—“Summary and Future Work”** summarizes the most significant results of this thesis and gives suggestions regarding problems that should be addressed in future.



## Chapter 2

# Related Work

This chapter offers an overview of literature published in the context of actuated tangibles on tabletops. The overview provides background information to understand the study, establishes the importance of this topic and justifies the raised research questions. To understand the line of arguments, this chapter is structured as follows:

Goal of chapter

**Section 2.1—“Review Characteristics”** presents the essential characteristics of this review such as focus, criteria or keywords and explains their effect on the review result.

**Section 2.2—“Literature Collection”** introduces the relevant articles, highlights their contributions and illustrates their relation to this thesis.

**Section 2.3—“Consequences for Thesis”** summarizes the noteworthy findings, explains the influence on the development of this thesis and emphasizes why research needs to be carried out.

### 2.1 Review Characteristics

This review is focused on research outcomes, theories or recommendations in the context of active tangibles on

Focus

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	<p>tabletops equipped with actuation technology. Of particular interest was research literature that contributes to the question how to balance user control and actuation. Therefore, this search included research literature that reveal knowledge how users experience the autonomous behavior of actuated tangibles.</p>
Finding and managing literature	<p>The literature search was mainly undertaken using the reference management software BibDesk<sup>1</sup> and the ACM Digital Library<sup>2</sup>. BibDesk provides an integrated search interface that is connected to the ACM database and is able to store automatically bibliographic information combined with associated file or web links. For literature on theoretical terms few books from the central library of the university<sup>3</sup> served as a source. The usage of the online search engine by Google<sup>4</sup> served finally as the third source for finding literature, whereas the internet search was mainly used for initiating a search routine.</p>
Searching with keywords	<p>To conduct a keyword search in databases or in the internet, a list of defined key terms was necessary. Since this thesis researches in the field of tangible tabletop interaction, the terms <i>tangible user interface</i> and <i>tabletop</i> were initially selected. To address the capability of forcing physical object to movement, we added the term <i>actuation</i> to the list. For covering user control aspects, the list contained the word <i>user control</i>. To narrow the scope of results, research outcomes should mainly be retrieved from user evaluations, so the keyword <i>evaluation</i> completed the list. In the course of the search the key terms <i>experimentation</i>, <i>psychology</i> and <i>perceived control</i> extended the list. In addition, while searching we discovered that the exclusive usage of keywords yielded unsatisfying results. Therefore we started to search by a boolean combination of at least two keywords, whereas each combination contained the term <i>actuation</i>, e.g., <i>actuation AND tabletops</i>, <i>actuation AND user control</i>.</p>
Criteria for inclusion or exclusion	<p>Basically this search focused on articles reviewed and published in academic databases. Research literature that was</p>

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<sup>1</sup>Reference management software: <http://bibdesk.sourceforge.net>

<sup>2</sup>ACM Portal: <http://portal.acm.org>

<sup>3</sup>Library: <http://www.bth.rwth-aachen.de>

<sup>4</sup>Google search: <http://www.google.de>

found with the internet search and showed no entry in an academic database was ignored. Instead the list of reference of the ignored article served as a further source. In the course of the reviewing process we discovered an absence of obviously direct related articles. Therefore this literature search included articles, that present not evaluated ideas or suggestions.

Each boolean combination of keywords yielded several result pages consisting of a list of hits. Due to the amount of pages, we limited the search to the first three. In the beginning, we only compared the keyword list of each hit with our keyword list. In case of a partial matching, we decided to read the abstract. As soon as we identified a slight relevance, we registered the paper using BibDesk. Otherwise we ignored the paper. The search with keywords finished at a point where no new relevant articles came to light. Afterwards every retrieved paper was read in detail and a summary of the corresponding paper was written. Articles with revealing content were categorized by priority. Independent from the priority, we searched the references of each paper, determined which of them are relevant and searched those in the database or the internet. The process repeated until a point of saturation was reached. For completing the literature search, we used the Google search. The purpose was to check for so far not discovered contributions.

Course

The collected set of literature is presented in a chronological way for illustrating the historical development. Each article is shortly introduced and its contributions are highlighted. In order to understand why a paper relates or contributes to this thesis, each section describes the relevance to this topic. A final analysis of the selected literature summarizes the findings and emphasizes the shortcomings of recent results and explains why further research needs to be carried out.

Organisation

## 2.2 Literature Collection

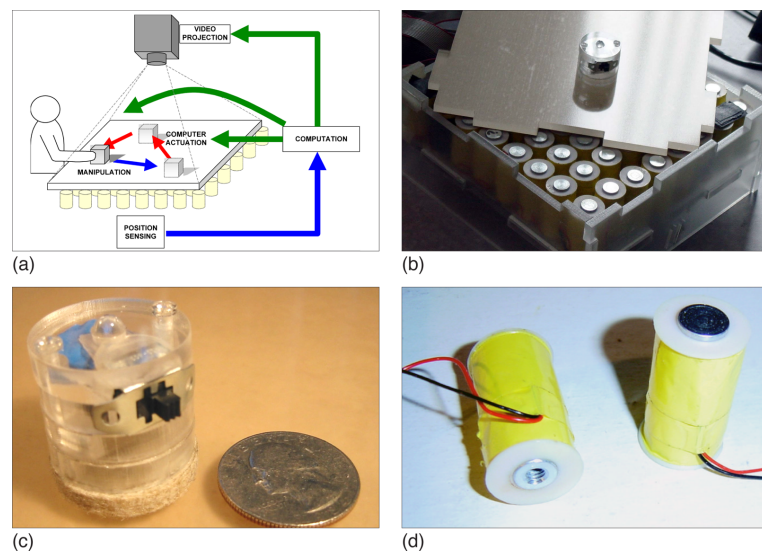
This section presents the most relevant and influencing projects with regard to this thesis. The number of articles

amounted to six.

### 2.2.1 Actuated Workbench

Active pucks on a tabletop

[Pangaro, 2003] developed a tabletop system (figure 2.1.a), that uses magnetic forces to move small pucks (figure 2.1.c) on the surface. The magnetic force is generated by triggering corresponding magnets (figure 2.1.d) from an array of magnets, that is located below the tabletop surface (figure 2.1.b). A puck is equipped with a permanent magnet for being capable of moving and an IR led for tracking its location.



**Figure 2.1:** The Actuated Workbench. **(a)** System overview. **(b)** Array of magnets with acrylic surface. **(c)** A tangible puck. **(d)** Two electromagnets from the array of magnets. (All figures from [Pangaro, 2003])

Resolve  
physical-digital  
inconsistency

The purpose of this project was to resolve the problem of visual and physical inconsistency. Present tabletop systems were unable to force objects on the tabletop surface to change the orientation or location. The consequence was that those systems could not guarantee the consistency between a physical object and its digital counterpart. Therefore the researchers developed the Actuated Workbench



that at the same time was the first of its kind. Additionally, they give insight in the motion control of the pucks and present an algorithm that enables the system to smoothly actuate the pucks.

After developing a system that met their design criteria, the research group focused on imagining interaction techniques and applications. They propose several functions from graphical user interfaces (GUI), e.g., undo or sort, and present extended versions for the physical domain. Remote collaboration or data visualization is proposed as an example application scenario.

Several application ideas are proposed

Unfortunately the research group did not conduct a user study for evaluating their developed system with regard to their application ideas. Anyhow, the proposed technological innovation serves as the base for several following projects ([Patten and Ishii, 2007, Weiss et al., 2010]). Furthermore other projects ([Pedersen and Hornbaek, 2011]) picked up the proposed GUI functions for evaluating interaction techniques. We argue that the research field of actuated tangibles on tabletops was significantly influenced by this work. Therefore we decided to start the review presentation with the Actuated Workbench.

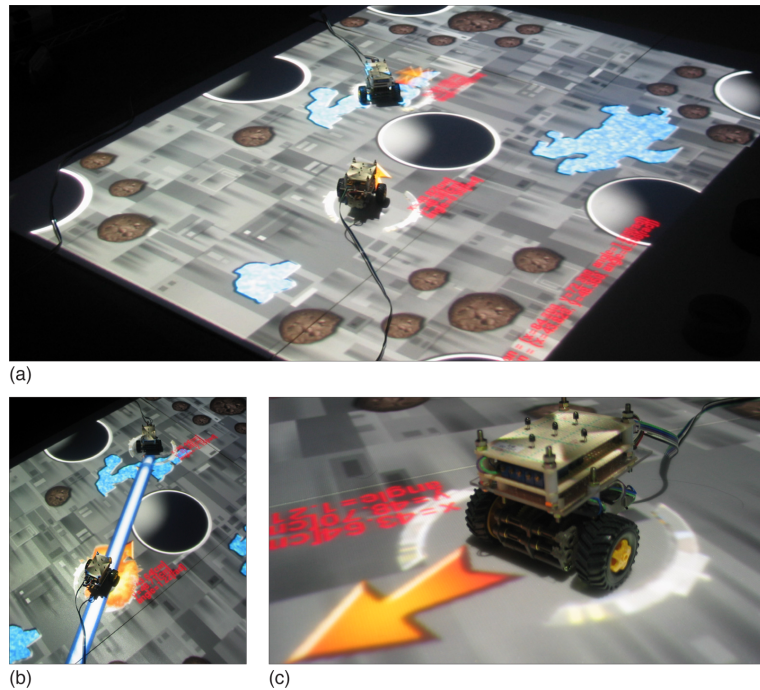
### 2.2.2 Augmented Coliseum

In their study, [KOJIMA et al., 2006] propose a game environment with small motorized vehicles on horizontal surfaces (figure 2.2.a). Each vehicle is equipped with phototransistors for sensing light intensity and a gradient marker is displayed over the set of phototransistors. As soon as a robot changes the position, the brightness values of the phototransistor will change. A software recognizes the changing and updates the coordinates of the displayed fiducial marker in way, so that the marker is displayed centered above the phototransistors again (figure 2.2.c). Finally, the position of the fiducial marker is used to visually augment the robots by rendering graphics at the corresponding coordinates.

Gaming with robots on horizontal surfaces

In the environment they propose, a war game is played

Robots are extended with graphics



**Figure 2.2:** The Augmented Coliseum. **(a)** Game environment overview. **(b)** Visualizing a laser cannon. **(c)** A motorized vehicle with displayed marker above phototransistors. (All figures from [Müller-Tomfelde and Fjeld, 2010])

with small robots. The robot can be treated as a actual toy in the real world. Each robot is augmented with projected graphics, e.g. a laser canon, a shield, or an explosion. Once a robot uses the laser cannon to attack, the attacked robot is augmented with an explosion graphic (figure 2.2.b). To simulate the impact, the corresponding robot gets actuated backwards.

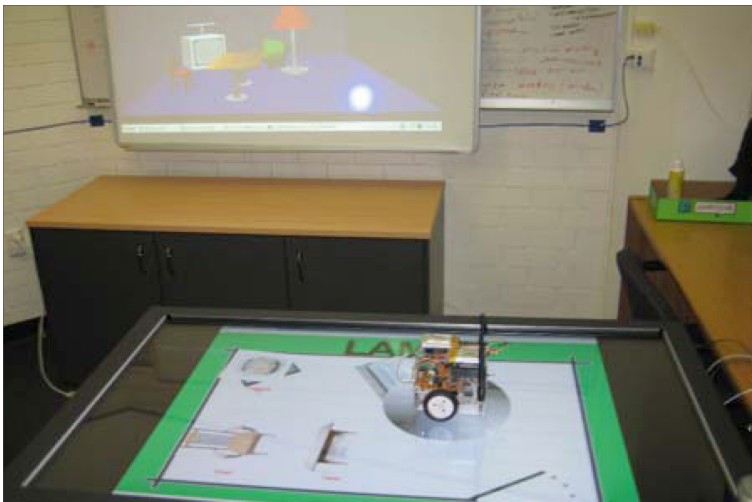
Graphical  
augmentation not  
evaluated, but  
promising

This study presents an environment in which motorized robots were augmented with digital information. Unfortunately, no study proved their statement, that the augmentation reinforces the fun of playing with such small robots in the real world. Anyway, the concept of augmenting physical objects seems promising and should not be restricted to a gaming environment. We think, their concept could be transferred into our context, for example for announcing upcoming actuated tangibles or visualizing the starting point of an actuated tangible.

### 2.2.3 Remote Active Tangible Interactions

[Richter et al., 2007] built a tabletop system based on the technical concept of [KOJIMA et al., 2006] (section 2.2.2—“Augmented Coliseum”). An extension enables the system to support distributed collaborative interaction with one shared motorized robot (figure 2.3). In other words, their system enables two users to execute a task together, although the two are spatially separated.

A distributed, shared robot on a tabletop



**Figure 2.3:** Remote Active Tangible Interaction. (Figure from [Müller-Tomfelde and Fjeld, 2010])

The goal of the work was to find out how users experience remote collaboration with shared resources. To evaluate the system, a furniture placement application was implemented. The application supports users to visualize the layout of a room of furnitures. Two users perform a furniture placement task with two conditions: mouse, and active tangibles. Based on the two conditions, the research group investigated the difference between tangible tabletop interaction and traditional mouse interaction.

Evaluated by furniture placement application

Unfortunately in their user study was only one single tangible available. For further research it would be interesting to test a similar system with more than one tangible and investigate the interaction between two distant users. However,

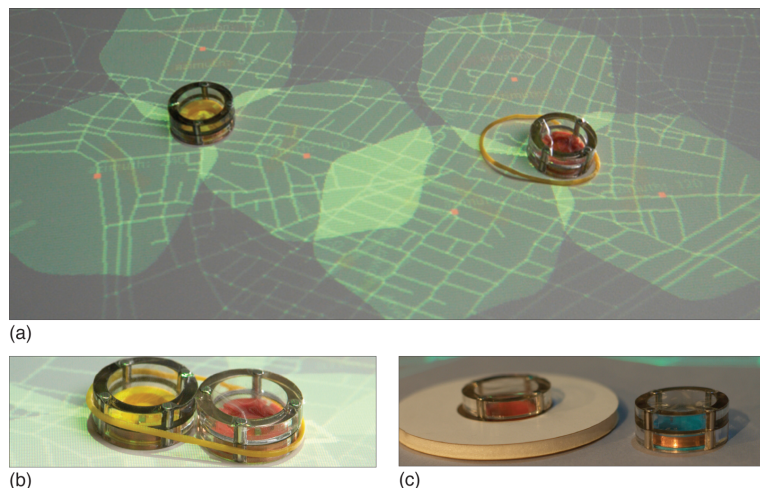
Only one tangible was shared

we think that exploring users in a distributed collaborative working environment makes absolutely sense. Hence, the actuation technology provides the tools to keep remotely shared resources in synchronization. We state, that using actuation technology in such a context will increase the overall interaction experience. To prove the statement, a corresponding study consisting of several tangibles needs to be conducted.

#### 2.2.4 Mechanical Constraints

Tangible constraints  
restrict puck  
movements

[Patten and Ishii, 2007] continued their work on the Actuated Workbench, that was presented in section 2.2.1—“Actuated Workbench”. Tangible constraints were introduced for restricting the puck movements. They constructed four tangible constraints: a rubber band (figure 2.4.b), a collar, an oval shaped ring, and a puck filled with sand. Depending on the constraint, a user can place it either on top of a puck or around the physical object. Each placement influences the systems ability to actuate the corresponding puck. For example, a collar is used to enforce a minimum distance between two pucks (figure 2.4.c).



**Figure 2.4:** Mechanical Constraints. **(a)** Cellphone tower application. **(b)** A rubber band to combine two pucks. **(c)** A collar to enforce a minimal distance between two pucks (All figures from [Patten and Ishii, 2007])

To evaluate the system, a simple experiment was performed, whereas the experiment had three conditions: using active pucks, using passive pucks, and using a mouse input device. The aim was to understand how actuation would affect the users' problem solving ability and how they respond to actuated user interfaces.

Experimental study  
with three conditions

For the experiment the group implemented a cellular telephone tower layout application, whereas the pucks represent the telephone towers in a network (figure 2.4.a). The software reacts to user interactions, e.g., moving a tower, and positions the remaining towers automatically in order to establish an optimized network coverage. Then a group of subjects had to solve a spatial layout problem. The task was to distribute the cellphone towers and achieve a desired coverage score in a fixed time slot.

Active pucks on  
tabletop represent  
cellphone towers

The main contribution of this work was, that the ability to use tangible constraints encourages the users to improvise with physical objects on the surface. The video analysis showed, that the participants used the tangible constraints as a tool to quickly try out problem solving strategies. As a result, the subjects were more successful in solving the problem solving task than with other interfaces.

Tangibles constraints  
encourage  
improvisation

Besides the main contribution for the first time a study revealed promising insight in the users' response to actuated tangibles. The research group gathered qualitative data by interviewing and video recording. A subjective analysis yielded that subjects uniformly found it frustrating, when the system occasionally moved a puck automatically and decreased the overall score of the problem solving task. According to the authors, future work should investigate techniques to disable or enable the computers' ability to actuate pucks.

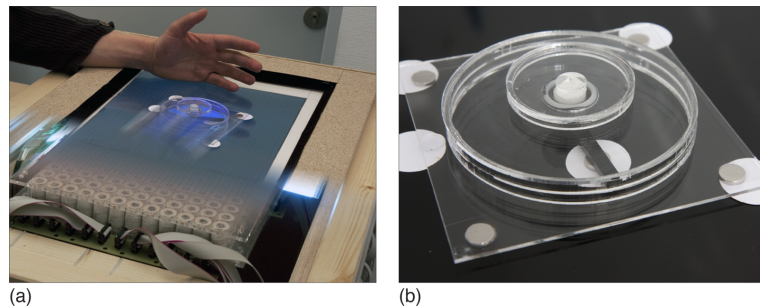
Automatic actuation  
is frustrating

### 2.2.5 Madgets

[Weiss et al., 2010] realized another actuated workbench (figure 2.5.a) based on magnetic forces (section 2.2.1—"Actuated Workbench"), that tracks their tangible objects, called madgets, by using a grid of fiber optics located be-

Tracking general  
purpose control by a  
grid of fiber optics

low the surface. They constructed five actuated general purpose controls: a knob, a radio button, a check box, an induction madget, a motor madget, and a bell madget. Each tangible consisted of agile parts, permanent magnets for applying magnetic force, and several gradient markers for tracking (figure 2.5.b).



**Figure 2.5:** Madgets tabletop system. **(a)** Surface with array of magnet. **(b)** A knob with agile part, attached magnets and markers. (All figures from [Weiss et al., 2010])

Actuating tangibles  
or its agile parts

The previously developed workbenches (2.2.1—“Actuated Workbench”, 2.2.4—“Mechanical Constraints”) were only capable of actuating rigid tangibles. In contrast, this project realized a tabletop system capable of actuating tangibles consisting of multiple agile parts. Besides providing low-cost physical tangibles, they proposed new actuation dimensions, such as height, force feedback, and power transfer.

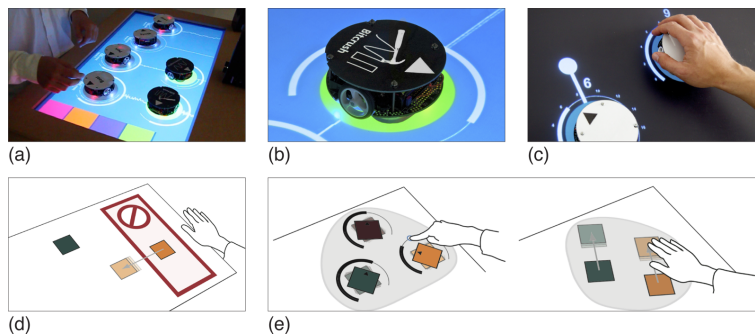
Future work indicates  
control issue

Although this project can be classified as a proof of concept and the research group did not evaluate the system, it provides one interesting recommendation. The future work announces, that the research group is currently working on feedback techniques to support the interaction experience with actuated tangibles. Additionally they are mentioning a reduced control caused by the automatic behavior. Therefore, it appears, that our concern on reduced control and the need for techniques to increase control is not unjustified.

### 2.2.6 Tangible Bots

Tangible Bots, briefly introduced in 1.1—“Thesis Context”, are motorized tangible user interfaces on tabletops (figure 2.6.a). The project was realized by [Pedersen and Hornbaek, 2011]. A marker is attached to the bottom and enables the system to track the physical objects (figure 2.6.b). For actuating a motor, the bots are additionally equipped with hardware for wireless communication. So, the tabletop system is able to steer the bots wirelessly by sending corresponding movement instructions. Since the motors need power, a set of included batteries serve as power supply.

Robots with fiducials on tabletops



**Figure 2.6:** Tangible Bots. (a) Tabletop surface with several Bots. (b) A motorized Bot. (c) How to use a Bot. (d) Interaction assistance technique (e) Grouping gesture technique. (All figures from [Pedersen and Hornbaek, 2011])

The research group states, that interaction with active tangible is “under-researched” and proposes four categories of interaction techniques: *interaction feedback*, *interaction commands*, *group interactions*, and *model-based interaction*. Each category contains different techniques to interact with active tangibles. For example, interaction assistance (figure 2.6.d) is a technique belonging to the *interaction feedback* category and describes a way to assist the user by moving a misplaced tangible to a valid area.

Proposing new interaction techniques

To evaluate the system with regard to their proposed interaction techniques two studies were conducted. A first study evaluates the usability of interaction techniques by comparing active and passive Tangible Bots. The set of

First study evaluates usability

tasks consisted of randomly selected rotation and movement tasks. An analysis showed that rotation benefits from the active Bots, whilst movements could be done more quickly with passive Tangible Bots.

Second study  
evaluates usefulness

In a second study, a music application was implemented for evaluating how active tangible interaction techniques support expert users. Participants had to interact with Tangible Bots, each representing a musical module, in order to arrange and mix music samples. The study collected information how a Tangible Bot was used and which interaction techniques were applied. The analysis revealed, that participants were able to create more complex and varied music, caused by the usage of the interaction techniques, such as grouping several pucks (figure 2.6.e).

Many contributions  
are missing

The most interesting result of this study is not the fact that the study revealed usefulness and usability. Similar to aforementioned studies, they concluded, that users preferred the active tangibles. In addition the participants were more effective in solving the tasks with active tangibles when compared to passive tangibles. The results did not surprise us. The interesting thing was their motivation for researching this field of human computer interaction. The researchers stated, that contributions in the field of tangible interaction that address questions how users interact with tangibles are missing. Furthermore they argue, that questions about potential benefits and drawbacks of tangible actuation are unanswered. We think, this statement confirmed our concern and underlines as well why research needs to be carried out.

### 2.3 Consequences for Thesis

Search show that  
research is  
necessary

The previous section presents the result of our literature search. Obviously, there is no study that addresses our questions directly or seems closely related to our concern. In summary, two kinds of contributions can be distinguished. First, research groups present their proof of concept and postpone promising ideas to the future. Second, mainly studies were conducted, that compare active tan-



gibles with other user interfaces regarding to efficiency or effectivity and emphasize the benefits of active tangibles. Unfortunately, a study that addresses directly the problem of loss of control with regard to the autonomous tangible behavior is missing.

Few projects casually revealed statements about user control. In *Madgets*, the future work mentions that actuation reduces control. Unfortunately, the term control is not further explained in this context. The *Actuated Workbench* and *Tangible Bots* propose techniques to control a group of physical objects. We concluded that the next phase of the thesis should provide us a better insight on perceived control within our context. The purpose was to learn about the cause and consequences of a loss of control. To achieve the goal, we decided to search in psychological literature, since it seemed to be the most promising approach.

Understanding  
control

As mentioned earlier, the review yielded few satisfying results regarding our goal to understand user control and its influence on interacting with actuated tangibles. Nevertheless, some findings were promising and influenced the further process of this thesis. We discovered several ideas, recommendations or methods, that we wanted to borrow for the purpose of this work.

Review influenced  
development of  
thesis

Participants in *Mechanical Constraints* mentioned a problem with the actuated tangibles. Apparently the majority of the participants were frustrated by the automatic behavior of the tangibles. The authors suggest a technique that could minimize the frustrations. This thesis picks up the authors' idea of providing a technique to disable or enable the actuation technology. A study should reveal how users interact with such an intervention technique and its influence on the perceived control.

Interrupt actuation  
processes

The *Augmented Coliseum* promises a better usable environment when augmenting physicals with graphics. Although they propose their concept in the context of a game environment, the idea of augmenting physical objects with additional graphics is promising. On a tabletop graphical output could be used to inform the user with regard to sudden actuation processes. In this way we assume that it is possible to minimize the surprise effect and somehow influence

Visual support

the perceived control. In addition, the researchers of *Madgets* confirmed our concern, since they mentioned for future work to identify adequate feedback techniques when interacting with actuated tangibles. Therefore, we concluded to identify variants of visual support for increasing the interaction experience.

#### Context of user study

In *Remote Active Tangible Interactions*, participants execute tasks in the context of a remote collaborative working environment. By using actuation technology, the shared resources on each tabletop are in synchronization. We find that such context represents a representative application scenario for future projects. Therefore we decided to design a corresponding study within this context in order to test appropriate support techniques.

#### Subjective data

The user studies in *Mechanical Constraints* and *Remote Active Tangible Interactions* collected subjective data from users by interviewing and video recording. In this way, the researchers were able to gather personal opinions and emotional impressions. For example, in *Mechanical Constraints* the automatic behavior frustrated the users, while in *Remote Active Tangible Interactions* the autonomous behavior increased the users' feeling of collaborating with a remote communication partner. We assume, for finding a way to balance user control and actuation, the users' personal opinion or perception is important as well. Therefore we concluded to use a similar approach for the purpose of this study in order to collect and analyze subjective data.

In summary, the literature review influences the development of this thesis in the following aspects:

- Before conducting a study, a better understanding of the term user control is necessary.
- We want to identify and evaluate techniques to interfere actuation processes.
- We want to identify and evaluate adequate visual support techniques.
- A distributed collaborative working environment seems promising for conducting a user study.

- For gathering data we want to use qualitative methods, such as personal interviewing and video recording.



## Chapter 3

# Initial Study

The findings of the literature review (2—“Related Work”) initiated the next phase of this work consisting of two phases. First, a literature study on user control in the context of psychology was conducted. Second, a brainstorming session was used to adapt the understanding of control to the context of actuated tangibles on tabletops. The current chapter describes the course and the result of these phases, whereas the general structure looks as follows:

**Section 3.1—“Motivation”** illustrates the purpose of this initial study and the anticipated goals.

**Section 3.2—“Control in Psychological Literature”** explains the term user control in a psychological context and serves as a preparation for the following brainstorming session.

**Section 3.3—“Brainstorming”** describes the brainstorming session, discusses the results and proposes a context dependent understanding of user control.

**Section 3.4—“Consequences for Main Study”** finally presents the roadmap for the further development of this thesis based on the findings from the literature review and the initial study.

### 3.1 Motivation

Understanding the term user control in general

The literature review showed that our concerns are justified and further research needs to be carried out. Apparently, there is no project directly addressing the question how to balance user control and actuation. Furthermore, we discovered that an understanding of the characteristics of control, the cause and the consequences of loss of control is missing as well. We concluded that before analyzing user control in the context of actuated tangibles, a better general understanding of the term user control is necessary.

Define context-dependent understanding of control

To understand the cause and consequences of control, we decided to explore psychology literature on human-human interaction. The goal was to borrow psychological theories on user control and adapt those theories to the field of human-computer interaction with focus on actuated tangible user interfaces on tabletops. Of particular interest was insight in how users may experience the reduced control and answers on how to minimize the loss of control.

Use subjective impressions as further data

For the purpose of defining a context-dependent understanding of the term user control, we additionally scheduled a brainstorming session. Subjective user impressions and concerns should be used for adapting the general characteristics of control to our context.

### 3.2 Control in Psychological Literature

Objective control

In general, the term *control* describes the actual existence of a causal connection between an action and its consequence. In other words, control is given, when a human has the ability to change the environment purposefully. For example, a computer user is able to avoid a critical data loss by using corresponding techniques to save the data, e.g., storing the data on an external disk drive.

Subjective control

Thereby, psychological literature agreed that besides the objective control a subjective control exists, whereas the term is also known as *perceived control*. The phenomenon

describes the human's subjective experience of being able to influence the environment. In general, subjective control is given, if a person believes in being able to influence or avoid aversive consequences of an event by reacting [Thompson, 1981].

But why is the perception of being in control so important? [Brehm, 1966] developed a theory that introduced the term psychological reactance. According to the author the term describes an aversive emotional reaction in response to restrictions that interfere on freedom and autonomy. Reactance is experienced whenever a free behavior is restricted or controlled. Later, [Deci and Ryan, 1987] argue that humans who sense a loss of control over the environment may experience more anxiety and stress. In [Rodin, 1990] the authors state that the feeling of being out of control lowers the self-esteem as well. According to [Depret and Fiske, 1993], humans can feel negatively about the environment and try to distance themselves, if control appears to be in the hands of someone else. Especially, when dealing with technology, such distancing could lead to a reduced use and finally less acceptance of the corresponding technology. In summary, the sensation of being in control is associated with emotional well-being of humans and leads to behavioral consequences.

Effects on loss of control

Across a variety of environments, from private workplaces with computers to public places with interaction technology, it seems that it is generally recommendable to have a sense of control. For providing insight into perceived control in greater detail, [Thompson, 1981] presented his concept of psychological control. This concept based on a conducted literature review on contribution to the field of control. As a result of this review, a typology of control was developed, that distinguishes behavioral control, cognitive control, information control, and retrospective control:

Four types of control: behavioral, cognitive, information, retrospective

**Behavioral control** implies that a human believes in behaving in a way, that aversive consequences of an event can be decreased. For example a user is working on a battery-powered laptop. Suddenly the device generates a beeping noise that indicates a critical battery state. Having the ability to plug in a power

supply helps the user to keep the computer from turning off. In this way the aversive consequences, e.g., unintended break or data loss, can be avoided.

**Cognitive control** refers to the ability to create cognitive strategies for reducing negative outcomes of an event. According to the author, cognitive strategies are for instance reinterpretation, downplaying, distraction, or avoidance. Although the consequence of an event is actually not less aversive, the usage of cognitive strategies provides the feeling as if the aversive of the event was reduced. For example, a user with his notebook at low battery state has no power supply around. The consequence is, that the beeping noise won't disappear and the machine finally turns off. Interpreting the beeping noise as reminder is a possible cognitive strategy. Now, the repeated beeping noise tells the user, that still several minutes are left for doing the most important work until the machines turns off.

**Information control** describes the ability of a human to predict upcoming events and its potentially negative consequence. For example, a notebook user is capable of predicting the moment, when the battery level becomes critical and a power supply is necessary in order not to lose valuable data.

**Retrospective control** refers to the ability to explain recent events or its aversive outcomes. In other words, a human is able to answer the question why an aversive event happened. For example, a notebook user is able to explain why his machine turned off and he lost valuable data. The suddenly stopped beeping noise and a black screen indicate, that the battery level was exhausted. The user knows, that his notebook does not suffer from a sudden hardware failure, but simply requires a power supply.

## **Conclusion**

From psychological literature we learned that the term control has several characteristics. Behavioral and cognitive



control enables humans to influence events in order to produce desired or prevent undesired outcomes. Having information control, people are capable of predicting events or their consequences. In contrast to information control, retrospective control describes the ability to explain events or the outcomes retrospectively. For the purpose of this thesis we narrowed the scope of user control to the following three characteristics:

#### CHARACTERISTICS OF USER CONTROL :

**Predictability:** Humans feel in control, if they are able to predict events or their outcomes

**Explainability:** Humans feel in control, if they are able to explain events or their outcomes retrospectively

**Influence:** Humans feel in control, if they are able to influence events, in order to produce desired or prevent undesired outcomes

Definition:  
*Characteristics of  
User Control*

In other words, humans feel generally a loss of control when they are not able to predict, explain or influence events and their outcomes. We assume that providing appropriate methods in order to enable users to predict, explain or influence events will minimize the loss of control regarding the environment. Now the question arises which methods are the most promising ones concerning actuated tangibles on tabletops, since their automatic behavior obviously conflicts with the users' desire to control the environment. Assume a tangible suddenly starts to move from one position to another. By default a user is not able to predict such an upcoming actuation process. Based on the theories from psychological literature it is likely that a user senses a loss of control.

Automatic behavior of tangibles conflicts with users' desire to control

In order to achieve a minimal loss of control we intend to design adequate methods to support a user while interacting with actuated tangibles. To achieve this, a context-dependent understanding of the characteristics of control is favorable. For that reason, we concluded to schedule a brainstorming session.

Find methods to minimize loss of control

### 3.3 Brainstorming

Finding conflicts,  
problems and  
potential solutions

Brainstorming is a creativity technique for generating ideas or raising questions that address a specific concern or problem. In case of thinking ways are needed to identify new aspects, brainstorming is a promising approach. For that reason, we scheduled a brainstorming session. The goal of this session was to learn about the users impression concerning the automatic behavior of tangibles. Of particular interest was insight in how users may experience the reduced control and what they suggest to minimize the loss of control. Few users have experienced actuated tangibles on tabletops so far, since the technology is only in its initial state. Therefore, the majority of the users are unbiased and we thought a brainstorming session seemed the most promising way.

#### 3.3.1 Procedure

Group of eight  
participants

In general, a brainstorming session consisted of a small group of people. Hence, 8 personally recruited volunteers participated in the brainstorming session. The participants ranged from 21 to 35 years and consisted of 2 females and 6 males. All subjects stated to be average computer users, while two subjects had experienced tangible user interfaces. None of the subjects was familiar with actuated tangible user interfaces.

Briefing the  
participants

In the beginning we explained all the participants the purpose and the course of this meeting. Since we did not want to take influence or shift the focus on particular ideas, none of our ideas and findings from the literature view were presented. To prepare all the participants equally, we additionally introduced the concept of actuation technology to them by showing our tabletop. One small physical object moved across a small part of the table for demonstrating the motion. Additionally we presented them a demonstration video from the institute, that showed the movement of a tangible object. The video was recorded for demonstration purposes for a conference paper.

The brainstorming meeting took place in a comfortable environment located at the university. The environment consisted of several circularly arranged tables with chairs and one blackboard. In the center of the table arrangement, candies and soft drinks were provided and we encouraged the participants to self-service. In general, two ways to express ideas are possible. Each participant either speaks aloud ideas or captures thoughts on a paper. A supervisor finally collects the ideas. We decided to use the latter one, since we experienced positive results using this approach. Therefore, each table was equipped with A5 record cards and a pen.

Writing on cards in a comfortable environment

To ensure a successfully brainstorming session, some rules were considered. No matter how unrealistic, funny or crazy the user statements were, everything was collected, since sometimes a crazy idea triggers a really helpful one. Therefore, we did not judge or criticize the mentioned statements. Criticism may intimidate the user and influence his creativity process. To make sure that the brainstorming session would end after a predefined period of time, we set the duration to 15 minutes. So, the users focus on the time interval and try the best in the given time.

Quantity, no critique

In the brainstorming session, we proposed an imaginary scenario, in which each participant executed a sorting task in coordination with a remote communication partner. Then the participants were asked to identify potential conflicts or situations that would impact their perception of control. Each participant was told to write each statement on a new record card. Then, the supervisor took the cards and pinned them on the blackboard one by one. In this way we encouraged the participants to develop other participants' ideas, or to use other ideas to create new ones. After the expiration of the time the session ended and all the participants discussed together the collected cards. Finally, closely related cards were spatially grouped on the blackboard.

Data collection

### 3.3.2 Results

Session yielded 36 cards

The brainstorming session yielded 36 cards with user statements. The user statements ranged from concerns about the automatic behavior of tangibles, general criticism regarding the presented tabletop system to subjective opinions concerning the control issue. In the following, the set of the statements is summarized followed by some example statements. Since the brainstorming session was held in German, we translated them into English for the purpose of this chapter.

Irrelevant statements

While examining the cards, we discovered statements, that addressed the limitations of the tabletop system. The participants pointed out that the puck motion is awkward and unnatural. Furthermore, they were concerned about the clicking noise while the tangible moved across the surface. The noise results from individual triggered magnets beneath the table. Hence, our tabletop system is a prototype and not functioning perfectly, such cards were excluded from the further analysis. Nevertheless, the statements indicate the importance of avoiding unnecessary disturbances. The table 3.1—“Irrelevant statements” presents a representative extraction from the collected cards.

User Statements	
1	“The bumping motion is a little bit disturbing”
3	“There is a clicking noise when objects are moving. That is strange”
4	“Objects are too big for the small screen”
5	“The motion looks unnatural. That would distract me”

**Table 3.1:** Irrelevant statements

Interference statements

Several cards contained content with concerns about the level of freedom for interfering with actuated tangibles. Apparently some participants would appreciate to be asked for permission before an object is actuated. Others confirm an interest in postponing an actuation process, until a user is ready. Furthermore, some cards propose ideas to switch the control between two users in order to guarantee equal control regarding shared objects. Besides interfering to gain control, some participants asked for a mechanism to support or take over an actuation movement in order to avoid waiting time. A small example of user state-

ments is depicted in table 3.2—“Statements regarding interference”.

	User Statements
1	“I would like to have the possibility to decide the time for actuation”
2	“I want to influence object movement, e.g. when crossing my working area”
3	“I want to be asked to allow actuation”
4	“I like to have complete control over the object when I’m interacting”

**Table 3.2:** Statements regarding interference

Another pile of cards contained demands for information in regard to occurring actuation processes. Participants argue, that they would prefer to know in advance the moment an object starts moving. In this way, a user is better prepared and less surprised. Otherwise the interaction experience would suffer from frustration or anxiety. Other participants state, that sometimes there is a need to see the initial point of a moved puck. For example being busy with a task could lead to not realizing the origin of a movement and not being able to reposition the corresponding tangible. Apparently users prefer as well, to see the complete movement path in advance in order to anticipate the motivation of the remote user. On two cards, users suggested an audible information before an actuation process started while others see the necessity to communicate directly with the remote communication user. Otherwise a collaboration would be too stressful and complicated. The table 3.3—“Statements regarding information”) shows examples of the written comments in our brainstorming session.

Information  
statements

	User Statements
1	“A vibrating tangible indicates future movement”
2	“Show movement path in advance to avoid collisions”
3	“Let a tangible beep as long as it is moving”

**Table 3.3:** Statements regarding information

Further cards contribute to the question how users may emotionally respond to actuation in general. A lot of participants explained, that objects not behaving as desired and expected would frustrate and annoy them. Especially if the behavior influences the success of the task. At the same

Emotion statements

time those people argue that they are unsure if they ever get used to the automatic behavior. Other participants argue that movements at all are distracting or scaring and they do not like the idea, that something moves as by magic. Their argument is, that the sudden movement would hinder them to execute a task and compared the automatic behavior with annoying alert popups in general graphical user interfaces. See an extract from the set of statements in table 3.4—“Statements regarding emotions”:

	User Statements
1	“I think I would stop a moving object if the moving frustrates me”
2	“Maybe it is frustrating when a remote user can interfere my current activity”
3	“The idea of not knowing what will happen would make me anxious”
4	“While executing a task, strange movements would probably distract me”

**Table 3.4:** Statements regarding emotions

Coordination  
statements

Other cards address problems regarding collaborated interaction and how to coordinate the access to shared objects. Lot of participants confirm the importance of coordinating the access to tangibles by communicating directly. In this way, it is possible to raise a claim to access a shared object on the table. Otherwise conflicts are unavoidable. Furthermore, they are concerned about situations, in which two users access an tangible simultaneously. Questions were asked concerning who is in control in such situations and how the system resolves them. The following statements represent examples of the written comments in our brainstorming session (table 3.5—“Statements regarding coordination”)

	User Statements
1	“I do not like the idea of getting unintended physical contact caused by sudden movement”
2	“When I use an tangible, I do not want to be interrupted”
3	“What happens when grasping at the same time the same tangible? Who is in control?”
4	“Several movements at once should be executed one after the other”
5	“When do I know, if the remote user is helping or annoying me?”
6	“Pin a tangible via an electromagnetic field to the surface, so I know it is in use”

**Table 3.5:** Statements regarding coordination

Benefits statements

Although the majority of the cards contained concerns, few

participants pointed out the positive aspects of the actuation concept. Participants liked the idea, that someone else is able to take over the objects. Although they see a loss of control, it would not impact the interaction experience negatively. On the contrary, they think it could increase the feeling of working actually together and sharing implies to give up control. The participants simply would accept the automatic behavior and wait until the movements have finished. Some example statements are illustrated in 3.6—“Statements regarding benefits”.

	User Statements
1	“I would just wait until movement has finished”
2	“The idea of guiding by moving a tangible is useful for disabled users”
3	“When something moves, I accept the fact. I trust the remote user”
4	“I do not see problems, on the contrary I see the helping character when collaborating”
5	“I would have more the feeling of working together, than with general tangibles”
6	“I like the idea that an unused object is able to free the space”

**Table 3.6:** Statements regarding benefits

### 3.3.3 Discussion

This brainstorming session was an approach to gather subjective impressions from users. We wanted to explore a first scope of potential concerns when interacting with actuated tangibles. Of particular interest was the insight in how users may experience the reduced control and what they suggest to minimize the loss of control. From psychological literature we have learned, that a user feels a loss of control, when he is not able to influence, explain and predict events or its outcomes within the environment. This section discusses the collected statements and explains our approach to adapt the understanding of user control to the context of actuated tangibles on tabletops.

Anticipated Goals

First and foremost, we have to admit that our participants were not able to interact with actuated tangibles. At that time this brainstorming session took place, our tabletop system suffered from several hardware problems. We are aware of the fact, that there is no evidence, if a brainstorm-

Limitations

ing session with users who experienced actuated tangibles in practice, would yield the same results. Since reflecting on imaginary scenarios is limited by the users' creativity, we assume that the findings would differ. Nevertheless, this brainstorming session yielded satisfying results since our findings either support or develop the findings from the projects, that we discussed in the literature review.

#### Predictability

The first characteristic of control is the ability to predict events or an outcome of an event. Based on the user statements from the brainstorming session, we assume it is necessary to provide information regarding upcoming actuation processes. Two participants suggested audible information to indicate a future tangible movement and three others proposed a vibrating tangible to announce a future movement. Furthermore, we assume that showing the destination or the movement path of an actuated tangible supports the predictability. The assumption bases on statements, that revealed the importance of being able to anticipate the automatic behavior of tangibles. See table 3.7—"Context-dependent meaning of predictability" for an overview on context-dependent predictability.

	Aspects
1	Predict an upcoming actuation
2	Predict the destination of an actuated object
3	Predict the movement path of an actuated object

**Table 3.7:** Context-dependent meaning of predictability

#### Explainability

The second characteristic of control is the ability to explain events or its outcomes. From the result of the brainstorming session we learned, that it is helpful to know the exact origin of an actuated tangible. In this way, the participant may be able to understand the cause or the intention of a movement. Furthermore, users are able to reposition the tangible to its original coordinate. Therefore we assume that it is necessary to provide information regarding the origin and cause of an actuation process in order to explain the movement retrospectively. See table 3.8—"Context-dependent meaning of explainability" for an overview on our context-dependent understanding of predictability.



	Aspects
1	Explain the origin of an actuated tangible
2	Explain the cause of an actuation process

**Table 3.8:** Context-dependent meaning of explainability

The third aspect of control is the power to influence events and their consequences. Apparently, several participants have the desire to interfere the actuation technology. The result of the brainstorming session showed an increased desire to disable, interrupt or postpone an actuation process. A similar observation was made in the *Mechanical Constraints* project by Patten and Ishii [2007]. Their participants demanded more control, if tangibles do not behave as expected. See table 3.9—“Context-dependent meaning of influence” for an overview on a context-dependent understanding of influencing actuated tangibles.

Influence

	Aspects
1	Avoid an upcoming actuations
2	Interrupt an actuated tangibles
3	Take over an actuated tangible

**Table 3.9:** Context-dependent meaning of influence

We state that providing techniques to support the aforementioned aspects will minimize the loss of control and increase the overall interaction experience with actuated tangibles on tabletops.

### 3.4 Consequences for Main Study

The previous section presents a context-dependent understanding of user control. Based on this characterization and the findings from the literature review, we are going to realize two kinds of techniques to support the user while interacting with an actuated tangible: visual support and actuation interference support. We assume, that those techniques will minimize the loss of control. According to predictability and explainability we are going to provide

Visual support  
methods

three different kinds of visual support. To predict an upcoming actuation, we design a technique, that visually indicates a future puck movement. For being able to explain the origin and the cause of an actuation process, the second method displays the starting coordinate of an actuated tangible. The third method finally provides information regarding the destination point and enables the user to predict the end of a tangible movement. Although several participants proposed vibrating or audible information for supporting a user, we decided to ignore those suggestions. First, our tabletop system is able to actuate tangibles across the surface but generating a controlled vibration effect is not possible so far. Second, providing audible information is problematic since such information is difficult to locate precisely within an environment and sometimes annoying as well.

Actuation  
interference

According to the desire to influence, we are going to provide a technique, that allows the user to enable or disable manually the actuation technology for a period of time. Although several other ideas to interfere came up, e.g., asking for permission or taking turns, we decided to implement a simple enable and disable technique. The reason is that this approach shows immediately the situations in which a users desire more control. In case a user feels a loss of control, he will probably use the technique to reclaim control. Besides coordinating the access to tangibles by an interference technique, participants of the brainstorming session suggested to communicate with the remote user directly. This suggestion was rejected, since we want to propose a supporting technique that does not suffer from language skills.

Perform sorting task  
with spatially  
separated user

In order to evaluate those techniques, we adopt the idea of [Richter et al., 2007] and observe participants in a distributed collaborative working environment. For that purpose, we realize the sorting task mentioned in the brainstorming session. Each participant is asked to place several tangibles in a particular order in coordination with a remote communication partner. The brainstorming session revealed several concerns about conflicts when coordinating the access to shared tangibles. Therefore, the remote communication partner enforces critical situations where two scenarios are distinguished. The remote user either

helps or annoys the observed user. In this way, we are hoping to collect information how the users respond to actuated tangibles depending on the provided support techniques.



## Chapter 4

# System Design

The further development of this thesis based on the decisions, that we made in the previous chapter. For preparing an intended user test, we had to deal with several hardware and software limitations. This chapter illustrates these challenges and how we faced them. To show this process, this chapter looks as follows:

**Section 4.1—“Tabletop System”** introduces the initial tabletop system and explains its most important components.

**Section 4.2—“Modifications”** highlights the problems with the initial tabletop and presents the improvements.

**Section 4.3—“Implementations”** presents the user tasks for the study and introduces the software, that we developed for the purpose of this study.

### 4.1 Tabletop System

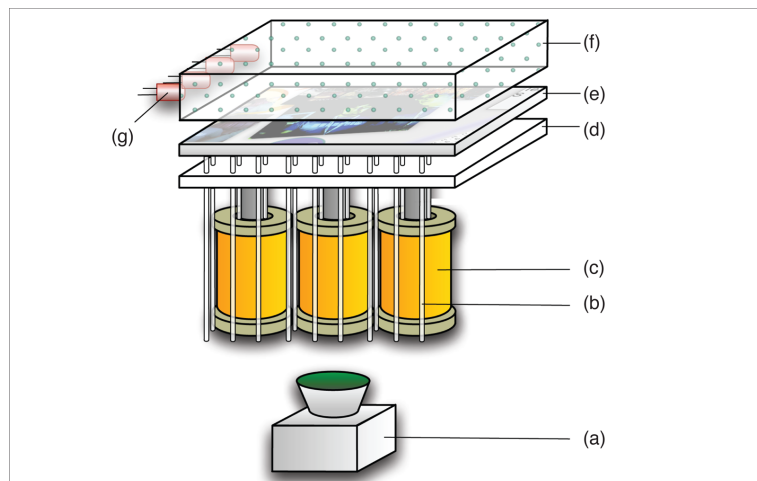
The tabletop system, that we are using is briefly introduced in section 2.2.5—“Madgets”. This section explains the relevant components in greater detail. The purpose is to under-

stand the limitations of the systems and which challenges we had to face in order to conduct the intended user study.

#### 4.1.1 Hardware

Surface consists of  
TFT panel,  
Endlighten layer, EL  
foil

A 24" (52,2 cm x 29,3 cm) TFT panel (figure 4.1.e) of a Samsung Syncmaster 2494LW monitor served as tabletop display. Beneath the panel an electroluminescent (EL) foil (figure 4.1.d) provided a consistent background light. On top of the panel a 6 mm Endlighten acrylic layer (figure 4.1.f) is mounted and a ribbon of 850nm LEDs (figure 4.1.g) around the layer projects infrared (IR) light into the surface.

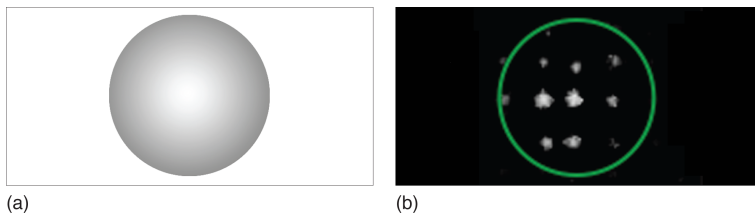


**Figure 4.1:** Madgets tabletop structure. (a) IR tracking camera. (b) Grid of fiber optics. (c) Array of electromagnets. (d) EL foil. (e) TFT panel. (f) Endlighten acrylic layer. (g) LED ribbon. (Figure from [Weiss et al., 2010])

Tracking through grid  
of fiber optic cables

A grid of fiber optic cables is mounted beneath the surface (figure 4.1.b). The number of cables amounts to 2146 (58 x 37). A gradient marker (figure 4.2.a) on the surface reflect IR light through the LCD panel to the fiber optic cables. To capture the reflections (figure 4.2.b), three cameras, each with an IR filter, are attached at the bottom of the table (figure 4.1.a). In case of a physical object on the surface is

equipped with gradient markers, the system is able to track them.



**Figure 4.2:** Tracking. **(a)** Gradient marker. **(b)** Captured reflection. (Figure from [Weiss et al., 2010])

Physical objects with attached permanent magnets on the surface are forced to movements by triggering decent magnets from the array of magnets beneath the tabletop surface. The array consists of  $19 \times 12$  electromagnets with a diameter of 19,5 mm and a length of 34,5 mm (figure 4.1.c). Each magnet is wound with enameled copper wire and the core is an iron rod with a diameter of 8 mm.

Actuating through  
electromagnetic  
forces

A mbed-microcontroller<sup>1</sup> is attached to the tabletop and is programmed to trigger the magnets. The mbed-controller receives trigger instructions wirelessly from an corresponding software application. Depending on the instructions the electromagnetic field has either a positive or negative charge.

mbed-microcontroller  
generates  
electromagnetic field

### 4.1.2 Tangibles

A tangible is made of transparent and lightweight acrylic consisting of agile subparts. A set of gradient marker beneath a widget enables the system to track them. The unique arrangement of markers serves as footprint and identifies a tangible.

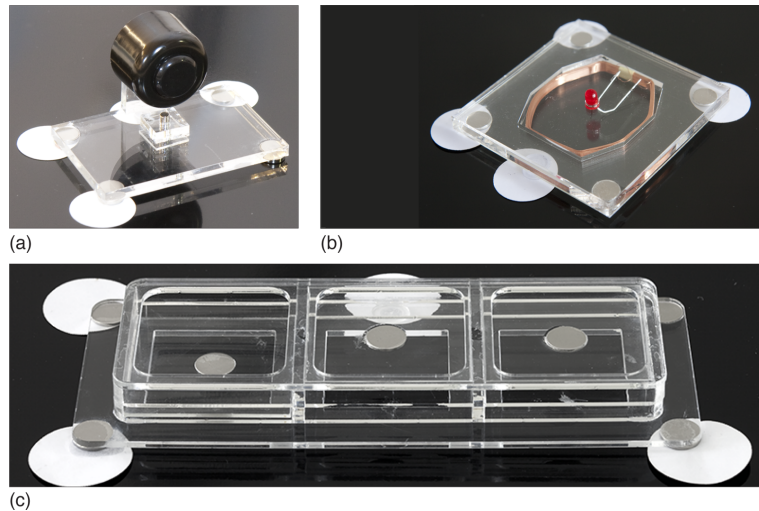
Identification by  
arrangement of  
markers

Attached permanent markers make it possible to actuate a object or its agile subparts respectively. For demonstration purpose, five tangibles, each with agile subparts, were constructed: a knob, a radio button, a checkbox, an induction

Actuating through  
permanent magnets

<sup>1</sup>mbed-microcontroller: <http://mbed.org>

tangible, a motor tangible, and a bell tangible (figure 4.3.a-c).



**Figure 4.3:** Madgets. (a) A bell. (b) An induction tangible. (c) A checkbox. (All figures from [Weiss et al., 2010])

### 4.1.3 Software Development

Mac OS X  
applications via  
Xcode

An application running on the Madgets tabletop system is implemented with Xcode 3.2. Xcode is an integrated development software for Mac OS X 10.6, that has been developed by Apple. Figure 4.4 illustrates the components, that are necessary to develop and run a software application on the tabletop system.

Discrete Grid  
generates touches

The Discrete Grid has two essential functions. First, it serves as a calibration tool for the cameras that are used to capture the IR light reflections. Second, the tool receives the camera frames and extracts from IR reflection dots on each frame a set of touches. The touches are finally distributed via the MultiTouchServer to the user application.

SLAPFramework  
identifies tangibles  
from touches

The user application receives the extracted touches and the SLAPFramework processes them. The framework searches for a touch pattern, that equals a registered tangible footprint and thus identifies the tangible. In the case, a tangi-



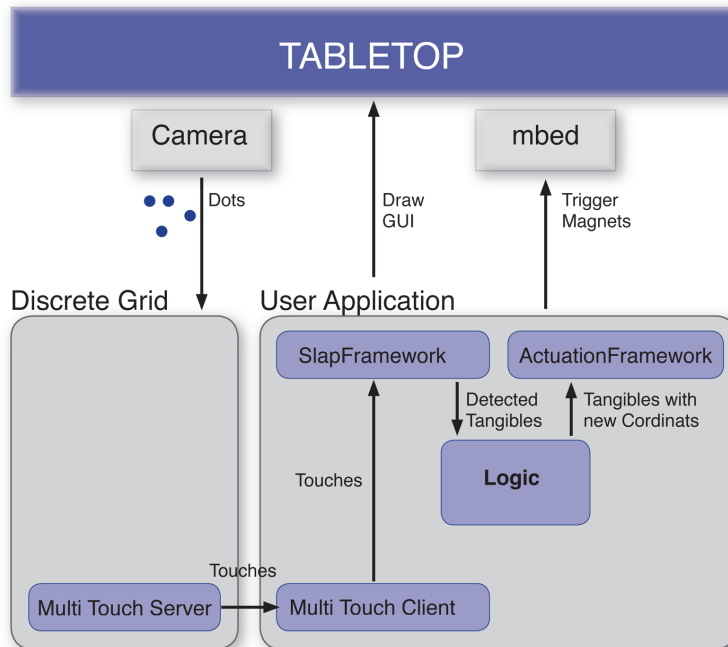


Figure 4.4: Madgets Software System

ble has been detected, the Framework visualizes the digital representation of the physical object on the tabletop surface.

The ActuationFramework is used to actuate detected tangibles on the tabletop surface. The framework provides the functionality to calculate the needed forces to move a specific permanent magnet in a particular direction. The implemented actuation algorithm is capable of moving complete tangibles or only agile parts of a tangible without changing the position of the actual tangible. To finally transmit the force values to the magnets, the framework offers the functionality to establish a wireless connection between the user application and the mbed-microcontroller. Once the force values are transmitted to the mbed-microcontroller, the corresponding electromagnetic fields are generated to actuate a detected tangible.

ActuationFramework calculates force values and sends trigger instructions

## 4.2 Modifications

To be able to conduct the intended user test, we had to overcome several software and hardware restrictions. This section presents the problems encountered with the base system. In addition, we will explain the procedures for resolving the issues.

### 4.2.1 Tracking with Vicon

Ambient IR light  
impairs tracking  
results

The proposed tracking technology of our base tabletop system uses reflected IR light to determine the location of a gradient marker on the tabletop surface. Unfortunately, ambient IR light influences the process of detecting markers negatively. We experienced frequently, that the tracking algorithm determines a marker position, although no marker was placed on the corresponding coordinate. In addition, we recognized a significant decreasing tracking quality in the course of the time. A completely dark room was no solution, since we needed ambient light to record the participants with a video camera. Therefore we concluded to look for a workaround to make the system more stable and less sensitive to ambient light.

Fiducial marker  
tracking system

An internet search yielded the reacTIVision computer vision framework<sup>2</sup>. The reacTIVision framework is an open source framework for tracking fiducial markers (figure 4.5.b) attached to physical objects. Because of the magnets there was no way to track from beneath the table. So we constructed a setting, where a camera senses the fiducial markers from above the surface (figure 4.5.a). While testing the construction, we discovered serious tracking problems resulting from hand motions. In many cases, our hands occluded a marker and caused the tracking problems. Apparently, sensing fiducial markers works best, when tracking from beneath the surface. Unfortunately, this option was not available and so we concluded to continue the search.

Vicon Hardware

Finally we decided to use the Vicon Motion Capturing Sys-

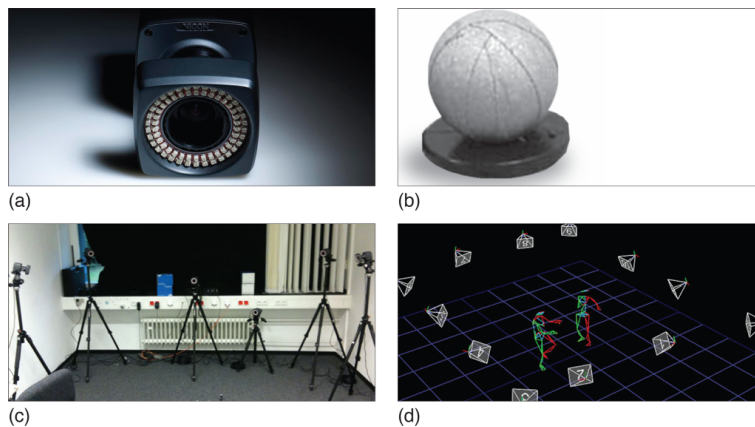
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<sup>2</sup> reacTIVision 1.4: <http://reactivision.sourceforge.net/>



**Figure 4.5:** Tracking with the reacTIVision framework. **(a)** Camera view. **(b)** A fiducial marker

tem<sup>3</sup> (Vicon) from the institute. The Vicon uses several infrared cameras (figure 4.6.c) for optically tracking three dimensional objects (figure 4.6.d). Each camera emits IR light and objects equipped with IR light markers (figure 4.6.b) reflect the IR light back to the cameras (figure 4.6.a). Although the system uses reflected IR light as well, the system is well known for being very reliable and precise.



**Figure 4.6:** Vicon tracking system. **(a)** IR camera. **(b)** Vicon marker. **(c)** Vicon setting. **(d)** Tracking 3D object.

To arrange the Vicon components and to calibrate the cameras, the guide<sup>4</sup> from the institute served as directive. For accessing the tracked marker data programmatically, we

Vicon software

<sup>3</sup> Vicon system: <http://www.vicon.com>

<sup>4</sup> Vicon calibrating: [http://hci.rwth-aachen.de/guide\\_vicon](http://hci.rwth-aachen.de/guide_vicon)

followed the Vicon developing guide<sup>5</sup> and used the provided software from the institute.

Vicon usage required system modifications

Unfortunately, the usage of the Vicon forced us to adapt the available tracking method and the actuation algorithm. The reason was that our design decisions concerning the tangibles (4.2.2—“Tangibles”) conflicted with the existing frameworks.

#### 4.2.2 Tangibles

Two new tangibles

For the purpose of our study two new transparent tangibles were built: a transparent, hemispherical puck and a transparent checkbox. The tangibles were constructed in the fabrication laboratory<sup>6</sup> (FabLab) of the university. We used a laser cutter<sup>7</sup> to cut single pieces from a acrylic plate. Finally, we glued the pieces together to form the objects. The hemispherical shell was bought in an usual handcraft shop.

Hemispherical puck with markers

For testing the reactIVision framework, we initially constructed a cyclic, acrylic token of 0.4 mm height and 40 mm diameter. On top of the token, a fiducial marker was placed (figure 4.7.a). To finally track the tokens with the Vicon, the fiducial marker was replaced by a Vicon marker (figure 4.7.b). A 1 mm permanent magnet is embedded in the token ground. Since the reflecting characteristic of a Vicon marker suffers from greasy hand traces, a hemispherical and transparent shell was mounted on top of the token (figure 4.7.c). As a useful side-effect, the shell additionally increased the tangibility of the puck.

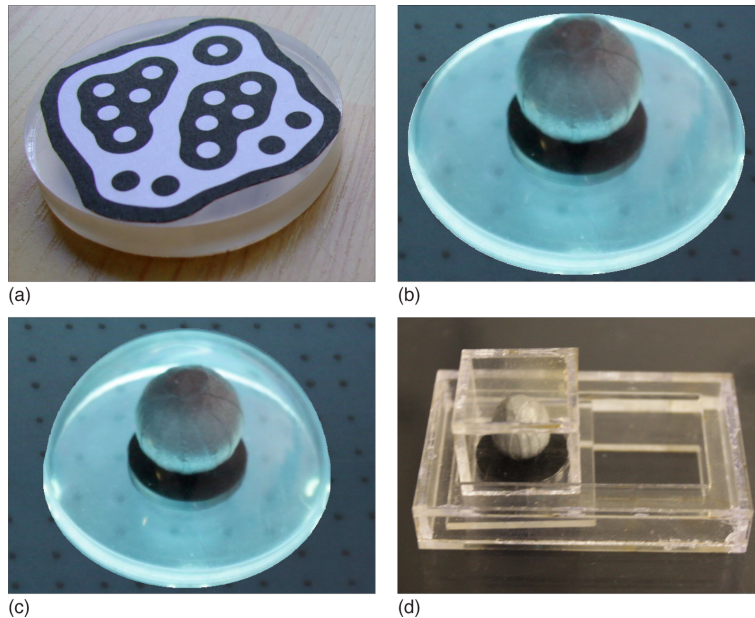
Agile switch

A second tangible, a switch (figure 4.7.d), was constructed. The switch consists of one agile clutch attached with a permanent magnet to the bottom. No other magnets are attached, since there was no need to actuated the complete object. We were only interested in actuating the agile clutch. The Vicon marker is located within the transparent cubic shell of the clutch.

<sup>5</sup> Vicon developing: <http://hci.rwth-aachen.de/vicon-development>

<sup>6</sup> FabLab: <http://hci.rwth-aachen.de/fablab>

<sup>7</sup> Lasercutter: <http://hci.rwth-aachen.de/lasercutter>



**Figure 4.7:** Tangibles. **(a)** Token with fiducial marker. **(b)** Puck with Vicon marker. **(c)** Final puck with Vicon marker and shell. **(d)** Checkbox with Vicon marker

The design decision to use pucks with a diameter of 40 mm was based on the limited tabletop space. Using pucks with such size makes it possible to move and position several pucks on the surface at once. Unfortunately the size of our pucks leaves no space for attaching more than one marker on top. The problem is, that the Vicon tracking algorithm requires a minimal distance between the markers for tracking and identifying 3 dimensional objects. Besides the fact of having not enough space to arrange several markers on the token, we discovered that several attached markers decrease the tangibility of our tangible. Therefore we decided to use only one marker for each tangible and implemented a special tracking method only for the purpose of our study.

Tracking problem

### 4.2.3 Tracking Method

The SLAPFramework (section 4.1—“Tabletop System”) receives touches, recognizes touch patterns and when possible identifies a tangible on the surface. To identify a tan-

SLAPFramework  
needs at least two  
markers

gible, more than one touch is necessary. Since our pucks consisted only of one marker, we were forced to modify the SLAPFramework. After studying the complex algorithm for identifying a tangible from a set of touches, we concluded to reject the idea of modifying the framework and implement own tracking approach.

Understanding  
tangible user  
interfaces

By default, the Vicon is not capable of distinguishing and identifying our pucks. Therefore a solution was necessary to distinguish them. Normally, the moment a tangible user interface is placed on the surface and is identified by the arrangement of markers, a corresponding digital representation appears on the screen. Whenever the tangible is manipulated, the digital representation gets an update accordingly. In other words, a tangible user interface gives digital data a physical form [Ishii, 2008]. Our approach is slightly different.

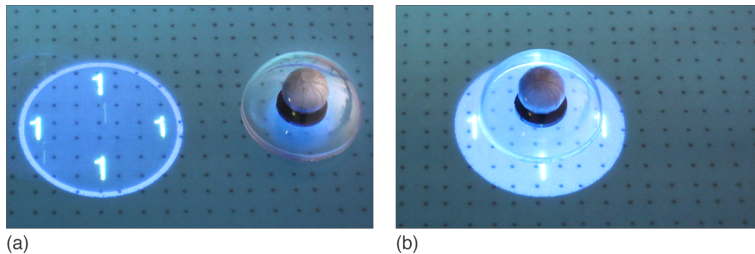
Tracking approach

In our system, a virtual puck exists to every physical puck, whereas each virtual puck has two states: tangible and intangible. At all times the virtual objects are visible on the screen. An intangible virtual puck has a pale blue colored inner area (figure 4.8.a). The inner area turns bright blue, when the virtual puck is in its tangible state. Once an arbitrary physical puck hits the inner area of a virtual object, its state turns from intangible to tangible (figure 4.8.b). At that moment, the physical puck gives the digital puck a physical form. The consequence is, that moving the puck on the surface will change the position of the virtual puck as well. On the other hand, the digital puck identifies the physical object. For example, in figure (figure 4.8) the puck is numbered with 1. As soon as the physical puck is removed from the surface, the state of the virtual puck turns to intangible.

#### 4.2.4 Actuation Algorithm

ActuationFramework  
depends on  
SLAPFramework

As mentioned earlier, the ActuationFramework of the institute provides the functionality to actuate detected tangibles on the tabletop surface. Unfortunately the framework is strongly connected to the SLAPFramework. The fact, that we do not the SLAPFramework for detecting our pucks, forced us to decouple both frameworks. After studying



**Figure 4.8:** Puck tracking. **(a)** An intangible virtual puck. **(b)** A tangible virtual puck.

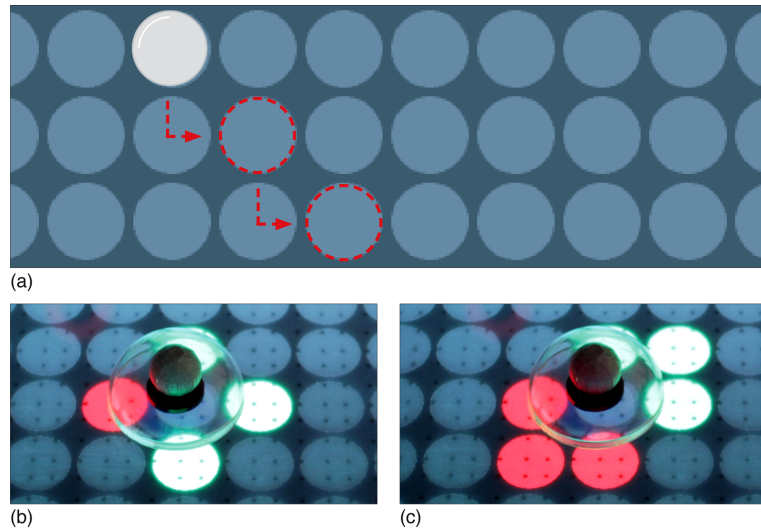
the ActuationFramework and a first approach to extract the ActuationFramework, we realized it would be a time-consuming undertaking. Therefore we decided to implement a simplified version of the current ActuationFramework for the purpose of this thesis .

Our study focused on actuating cyclic pucks. There was no need for rotating or moving complex agile parts of a tangible. So, we decided to realize a simple tangential actuation [Weiss et al., 2010] based on the concept of [Pangaro, 2003]. The research group introduced an actuation algorithm, that moves physical objects across a tabletop surface in a way they call *Manhattan motion* (figure 4.9.a). They used this term since the surface was virtually divided into a grid of cells in a linear “Manhattan” fashion (in straight lines at right angles to each other). Using this approach, their system was capable of moving a puck to any grid cell on the table by consecutively triggering the electromagnets in the neighboring cells regarding the puck location.

Manhattan motion

For the purpose of the intended user tasks, we distinguished two tangential movements. A puck moves either in horizontal/vertical or in diagonal direction. For both cases we designed a way to trigger the most adequate neighboring magnets. Figure 4.9 illustrates our results. In figure 4.9.b the generated electromagnetic fields force the puck to move in horizontal direction. Figure 4.9.c presents a solution to move a puck in diagonal direction. In order to achieve a reasonably smooth motion, the magnets are triggered along a path 20 times a second. We have to admit, that the motion is not as good as expected, but acceptable for the purpose of our intended user test.

Diagonal and horizontal/vertical movement



**Figure 4.9:** Puck actuation. (a) Manhattan motion (b) Horizontal direction, (c) Diagonal direction.

### 4.3 Implementations

For the purpose of conducting a user test, we developed a software application. The development of the application consisted of three phases. The initial motivation for developing a software based on the need to control the array of magnets by using a graphical user interface. At the time, this thesis started no such software was available. Later, the software was updated in order to be usable for our planned user test. The structure of this section represents this development process:

**Section 4.3.1—“Magnet Array Interface”** presents our developed graphical user interface to control the array of magnets and explains how to use the software.

**Section 4.3.2—“User Test Design”** describes the user tasks, illustrates the task user interface and explains how to control the user test with our software.

**Section 4.3.3—“Wizard of Oz”** presents our approach of simulating the presence of a remote communication partner.



### 4.3.1 Magnet Array Interface

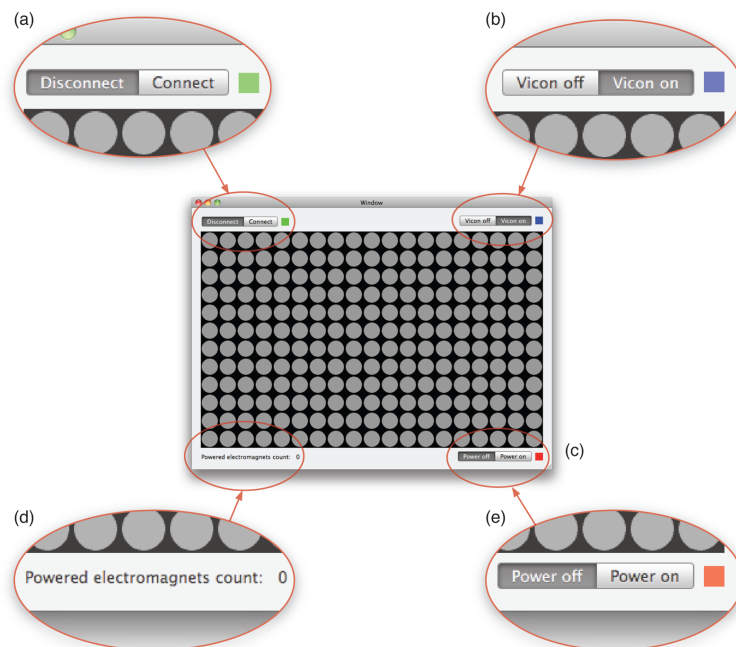
The interface provides two functions. First, it offers tools to trigger magnets, in which two kinds of trigger actions can be distinguished: trigger single magnets or trigger several magnets consecutively. Second, the interface provides a view, that visualizes the positions of tracked Vicon markers.

Trigger magnets and display markers

#### Usage

When the software is running a main window appears that contains three buttons, one label and one view (figure 4.10). These elements enable the user to interact with the magnets and simultaneously provide an overview of tracked markers.

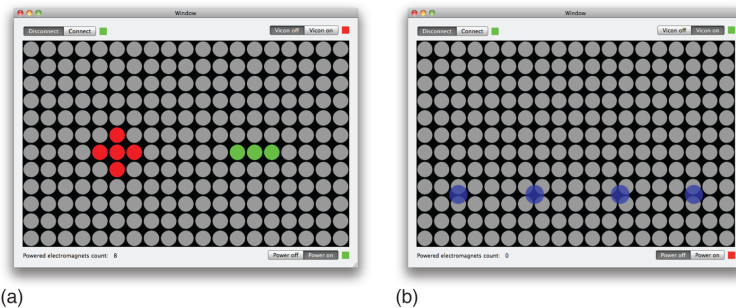
GUI with three buttons, one view, one label



**Figure 4.10:** Magnet array interface. **(a)** Hardware connect button. **(b)** Vicon connect button. **(c)** Magnets view. **(d)** Power magnets label. **(e)** Power on button.

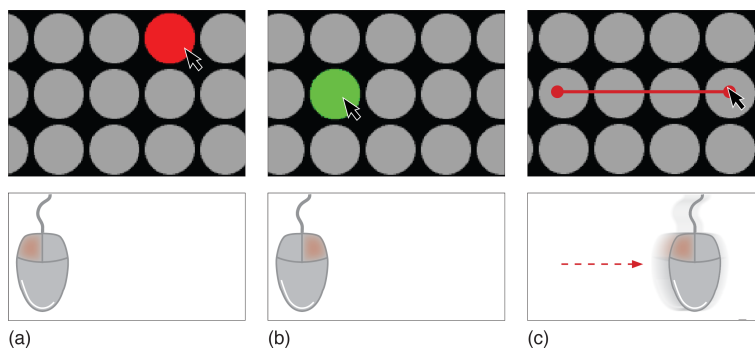
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Hardware connect button	Clicking the <i>Connect</i> -button (figure 4.10.a) establishes a connection to the array of magnets via the mbed-mircocontroller. In case the connection establishment succeeds, the red colored box turns green and signals the user, that the hardware was found.
Power on button, count powered magnets label	To generate finally an electromagnet field, the <i>Power</i> -button (figure 4.10.e) needs to be activated as well. Even though a connection could be established, if the power is off, no magnets are triggered. Deactivating and activating again will reset all magnet charges at once. In addition, use the <i>count</i> -label (figure 4.10.d) to see the number of currently triggered magnets.
Vicon connect button	For establishing a connection to the Vicon tracking system, the <i>Vicon</i> -button (figure 4.10.b) needs to be triggered. While searching the Vicon in the network, the red color turns to blue and signals the user, that the search is in progress. Again, the connection establishment is successful if the box color turns green.
Magnets view	The <i>Magnets</i> -view (figure 4.10.c) displays a grid of circles, that represent the array of magnets beneath the tabletop. If the hardware is connected and the power is on, the view visualizes the triggered magnets by showing the corresponding color of the charge (figure 4.11.a). Additionally, if the software successfully establishes the connection to the Vicon, the view displays the positions of tracked Vicon markers by showing blue colored circles at the corresponding coordinates (figure 4.11.b).
Trigger magnets with mouse	To trigger single magnets or several magnets consecutively, the software needs to be operated by a mouse pointing device. Three different mouse gestures are available for triggering magnets: left-click, right-click, and drag and drop (figure 4.12.a-c): <ul data-bbox="606 1803 1339 2013" style="list-style-type: none"><li>• A single <i>left-click</i> triggers a magnet with a positive charge. Left-clicking again undoes the trigger action.</li><li>• A single <i>right-click</i> triggers a magnet with a negative charge. Right-clicking again undoes the trigger action.</li></ul>



**Figure 4.11:** Magnets view. **(a)** Five triggered magnets with positive and three triggered magnets with negative charge. **(b)** Four tracked markers.

- A *drag and drop*-gesture triggers several magnets consecutively. Select a starting magnet and drag the mouse pointer to a designated target magnet. While dragging, a red connection line is displayed. After releasing the mouse button, our actuation algorithm decides which magnets along the path need to be triggered. To undo the action the mouse gesture needs to be repeated.



**Figure 4.12:** Mouse gestures. **(a)** Left-click. **(b)** Right-click. **(c)** Drag and drop.

For testing purpose and preparation for the distant user study, the interface optionally visualizes the *Madgets*-view on the tabletop screen (figure 4.13). Charges and marker visualizations are visible as well. Each visible circle is exactly located above an actual magnet. To display the tabletop view, use the *Tabletop*-item within the main menu and

Tabletop view

select *Show Window*.

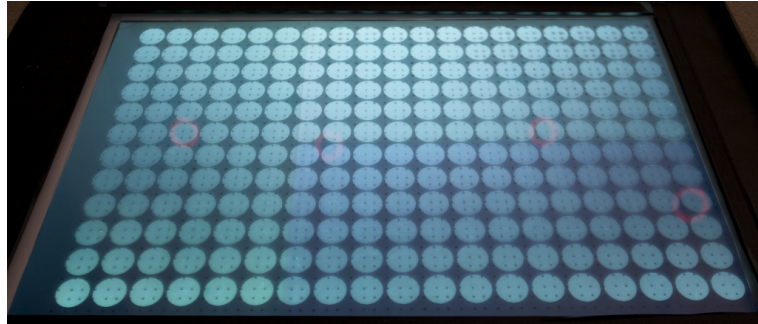


Figure 4.13: Magnets view on tabletop

### 4.3.2 User Test Design

According to the findings from the literature review and the results of our initial study, we designed a user study in the context of a distributed collaborative environment. Participants execute several tasks in cooperation with a spatially separated communication partner. This section describes the base task, its variations and the task user interface. Although there is no second table and no remote communication partner exists, this section ignores the fact for explanation purpose.

#### Task Description

Sorting a set of shared pucks

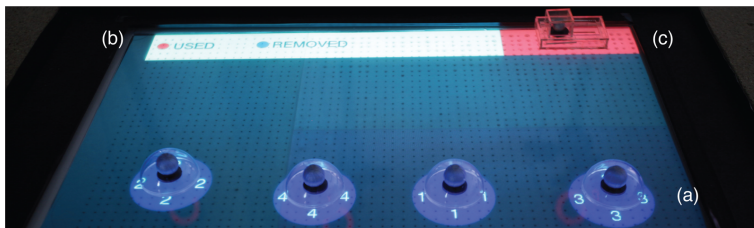
In our user test environment each participant executes several tasks in cooperation with a spatially separated communication partner. We decided to design simple sorting tasks, in which a participant is asked to place a set of shared physical pucks in a certain order. The challenge is to coordinate the execution with the remote partner and behave adequately to remotely actuated pucks in order to successfully perform the sorting task.

### Task User Interface

Graphical elements with textual content use the English language. Although the tasks contain very few situations in which reading is necessary, we considered it important, that all participants have no difficulties in understanding the textual content. Since we knew, that all participants have the ability to understand the English language in speech and writing, no German version of the interface elements was implemented. On top of the tabletop surface four tangible pucks are located with predefined coordinates. To each puck exists a digital counterpart, that is visualized beneath the puck and shows the current number of the puck (figure 4.14.a).

English GUI  
language

Pucks augmented  
with digital numbers



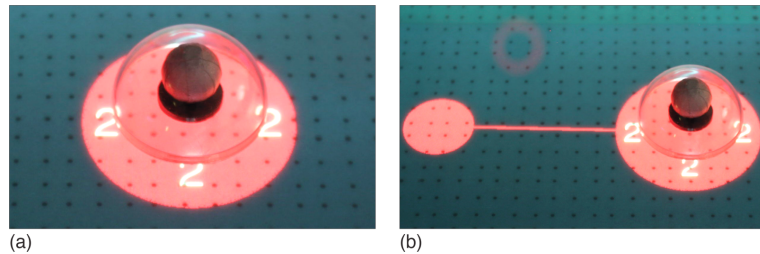
**Figure 4.14:** Overview of the task user interface. (a) Four tracked pucks. (b) Agenda to understand token state. (c) Switch to disable actuation technology.

Each puck can take three different colors: blue, red, grey. Normally, a puck is blue. The puck color turns red, if the remote communication partner holds or moves a puck (figure 4.15.a). As soon as the remote user removes a puck from the table, the color turns to grey. An displayed agenda on the surface shows the user the state meanings all along (figure 4.14.b). If the puck is moved, a user will experience a resistance. Releasing the puck will actuate the object back to its initial point (figure 4.15.b).

Pucks are colored

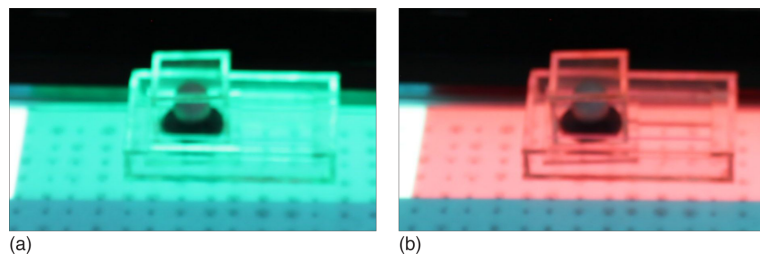
Besides the four pucks, a physical switch (figure 4.14.c) is located on the surface. The switch enables a participant to disable or enable the actuation technology and comes with the colors green and red. A switch is red (figure 4.16.b), if its functionality is not available within a task. Otherwise the switch color turns green (figure 4.16.a). In case a user tries

Tangible switch



**Figure 4.15:** Puck. **(a)** Currently in use. **(b)** Initial point of a moved puck.

to use the switch although its functionality is not available, the clutch switches back automatically by triggering a magnet beneath the switch.



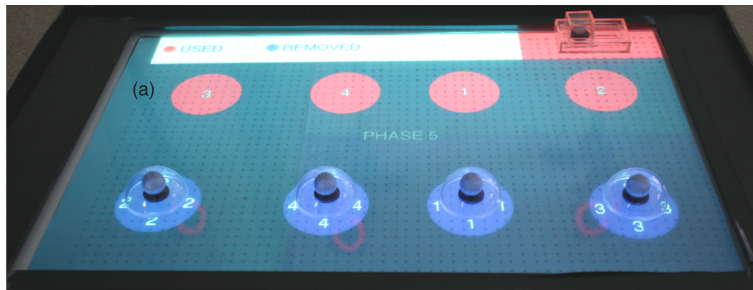
**Figure 4.16:** Tangible Switch. **(a)** Switch functionality is available. **(b)** Switch functionality is not available.

Designated puck  
order information

In the beginning of a sorting task an information appears on the screen (figure 4.17.a). The information shows the designated target order of the pucks. After ten seconds this information fades away and the participant is allowed to place the pucks in the particular order. The decision of showing the designated order only for few seconds was made, because we hoped, that sometimes a participant forget the target order or is at least uncertain about it. We assumed that such situations give insight into the user behavior with the remote communication partner.

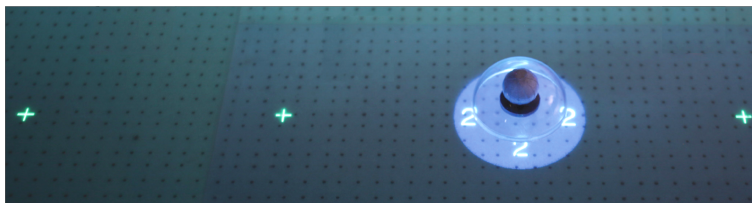
Puck placement  
coordinate

In order to set the desired puck order, each participant has to move the pucks on the surface. The surface displays four small green crosses and each cross indicates where to position the four pucks (figure 4.18). Once, all pucks are located on the crosses, a counter appears and counts down from



**Figure 4.17:** Task user interface. **(a)** Designated puck order information.

10. In this way, we provide the participant the possibility to tell the system, that he has finished sorting. If a participant becomes uncertain regarding the selected puck order, then he is allowed to update the order accordingly within the 10 seconds. The moment the counter turns 0, the task is finished and the participant finds out, if the selected puck order is correct.



**Figure 4.18:** Puck placement crosses

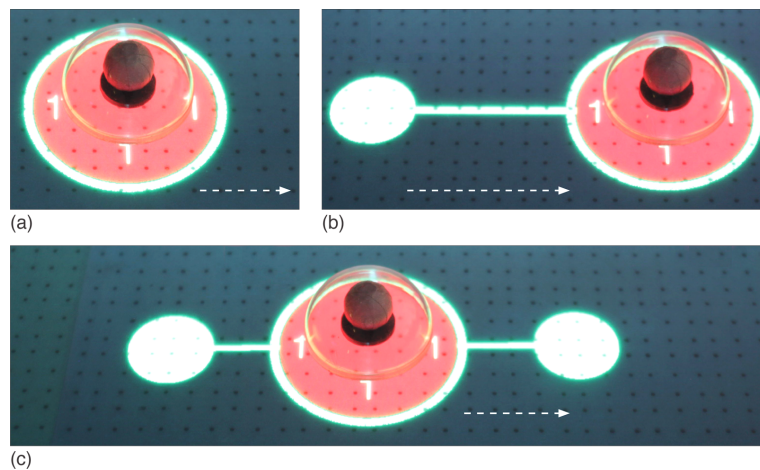
Based on what we have learned in the initial survey, we designed three different kinds of visual support when interacting with actuated tangibles. The goal was to inform the user about ongoing actuation processes. Additionally, each visual support technique blinks for a period of three seconds. The blinking effect signals the user an upcoming actuation process. The three kinds of visual support (figure 4.19.a-c) look as follows:

Visual support

- A halo around a puck to announce an actuation process.
- In addition to the halo, the initial point of an actuated

puck along the movement path is visible

- Combines the previous methods and additionally shows the destination point of an actuated puck



**Figure 4.19:** Visual support methods. (a) Halo around puck. (b) Initial point along with movement path. (c) Initial and destination point along with movement path.

### Test Control

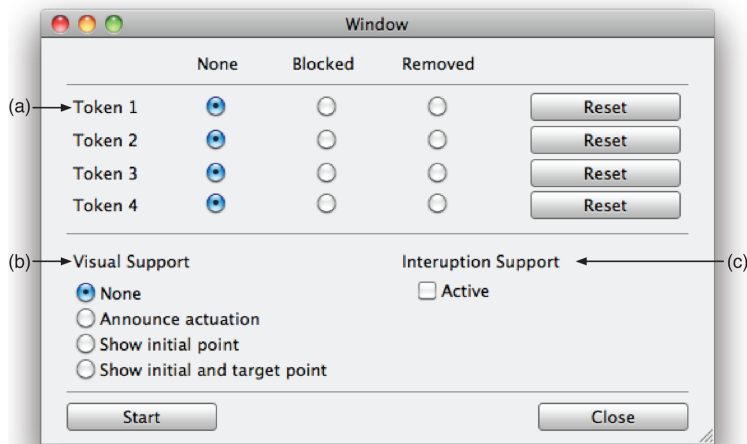
Open control window

To run the set of user tasks we extended our software. Start the user test by clicking the *Usertests*-item in the main menu and select *Sorting Task*. A new window will appear that provides the tools to start and control the user tasks (figure 4.20). In order to select a desired support method for a test unit, the window presents several graphical elements (figure 4.20.a-c).

Select user support and start

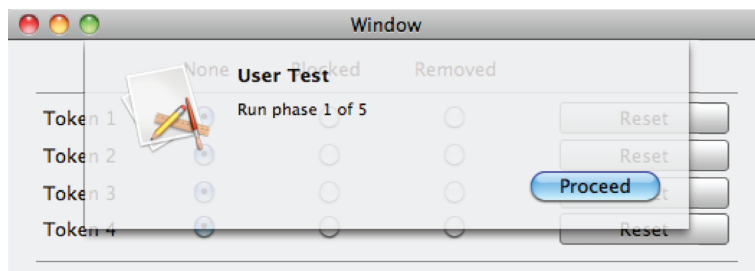
Before starting a test unit, the evaluator defines the kind of visual support. In the next step, the evaluator decides if the participant is allowed to enable/disable the actuation technology. By clicking on the *Start*-button the test unit starts and a small information panel appears (figure 4.21). After confirming the *Proceed*-button, the actual task is initialized and the user is able to see the previously mentioned user interface on the tabletop display. Since a test unit consists of five sorting tasks, the panel appears five times as well.





**Figure 4.20:** User task controller window. (a) Puck state control buttons. (b) Options for visual support. (c) Option for enable/disable actuation.

The panel appears automatically if all pucks are located at the virtual crosses and the counter hits zero. After finishing a test unit, the evaluator starts the next unit the same way.



**Figure 4.21:** Next Phase Panel

### 4.3.3 Wizard of Oz

As mentioned earlier, the user tasks should be executed in the context of a distributed collaborative working environment. A participant executes a simple sorting task in cooperation with a spatially separated communication partner.

Second tabletop is not available

Due to the fact of financial and time restrictions, only one tabletop was available and a solution was needed to simulate the existence of a remote communication partner.

Simulating user behavior

In the section (5.3.3—“Test Procedure”) we summarize potential situations, that may cause problems while interacting with shared tangibles. So we needed a way to enforce such situations by moving pucks on the table or simulating that the remote users holds a puck. The question was how to create an environment, that meets our requirements.

Implementing remote user response complicated

In the beginning, we had the idea of implementing computer responses to user activities. While a participant tries to place the pucks in a particular order, an algorithm should automatically enforce conflicting situations. Soon we realized the difficulties in anticipating user actions and implementing potential reactions. Furthermore, the present hardware for generating electromagnetic fields did not work perfectly, so that we sometimes had to trigger the magnets manually repeatedly. Therefore we concluded to implement a more flexible way to simulate the behavior of a remote communication partner.

Using the Wizard of Oz approach

For this purpose, we realized the Wizard of Oz concept. In this approach a human “wizard” simulates the responses of the system. The wizard controls the system to simulate appropriate output according to user input. In our case, the wizard simulates the responses of the remote communication partner and enforces conflicting situations. To guarantee impartiality, the participants are not aware of the wizard and the fact that a remote tabletop is not available.

### Usage

Extended *Magnets*-view shows numbered pucks

The Magnet Array Interface (4.3.1—“Magnet Array Interface”) makes it possible to move pucks on the tabletop surface by executing mouse gestures. In order to sort pucks in a particular order or to interfere with the users’ ambitions to achieve the correct puck order, we needed to see the numbers of the pucks. For that reason, we extended the *Magnets*-view. After initializing a user task, the view visualizes the position of tracked pucks and additionally shows

their number. In contrast to the tabletop user interface, the wizard sees the designated target order at any times. In this way, the wizard does not need to remember anything and can focus on simulating remote user responses (figure 4.22).

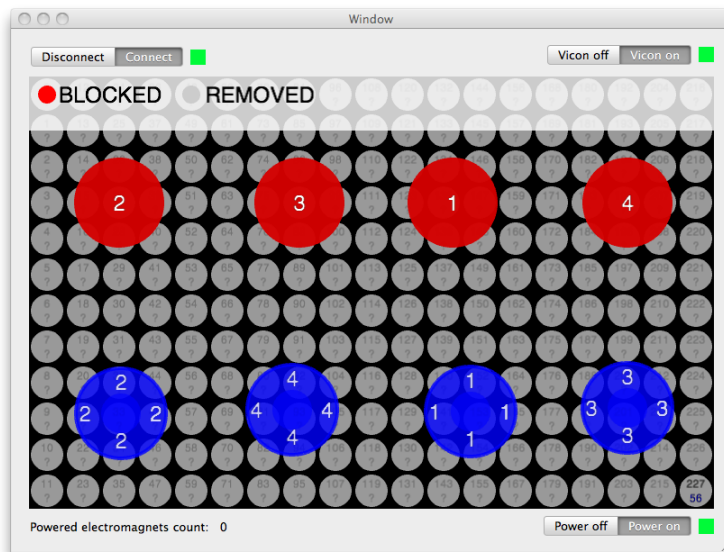


Figure 4.22: Extended *Magnets-view*

By using the initially proposed *Drag and Drop*-mouse gesture, the wizard is able to force specific pucks on the tabletop surface to movements. The extended *Test Control*-window provides the user interface to simulate that the remote user has removed a puck from the surface or holds a puck (figure 4.20.a).

Move pucks via  
mouse



## Chapter 5

# User Study

This chapter finally evaluates the designed support techniques and examines the user's behavior when placing a set of shared pucks in coordination with a remote communication partner.

### 5.1 Format

#### 5.1.1 Experiments

This study is used to judge the effect of active tangibles on users and to discover specific problems with them. Therefore this evaluation was performed as an experimental study in which users had to carry out a set of tasks. We applied the within group approach, in which each user executes all tasks.

Within group  
evaluation

All participants execute the tasks in coordination with a remote communication partner. Due to the fact, that no second tabletop system was available, we created a workaround. A user interacts with a wizard that users believe to be the remote user. In reality unseen wizard actions respond to the user's interactions. The advantage of applying the so called Wizard of Oz approach is, that in this way we were able to simulate the presence and the action of a

Wizard of Oz  
experiments

remote communication partner.

Fixed task order but randomly forced situations

The sequence of tasks did not change from user to user. The Wizard of Oz was able to force some situations the user had to respond to. Each user was forced to deal with the same situations, since the user's behavior is not foreseeable the order of the situations changes, depending on the currently underlying situation.

### 5.1.2 Data Collection Techniques

Collecting data from video, interview, questionnaire, thinking aloud

In order to gain qualitative information several qualitative evaluation techniques were applied in the process of the study. While executing the task each user was encouraged to speak aloud if a problem occurred, an unexpected event happened, or frustration spread. A video camera pointed at the interaction surface such that the participants' hand motions and posture while executing the tasks could be analyzed later. In case interesting behavior was observed while executing the task, a participant was shortly interviewed after the test. Finally, each user was asked to answer a post-questionnaire concerning how he experienced the automatic behavior of the actuated tangibles. The form consisted of four pages separated consisting of five-point Likert scales, yes-no questions or statements respectively and forms. (appendix B—"Questionnaire").

### 5.1.3 Test Environment

Unflexible equipment

The available equipment is very immobile, since a lot of hardware components must be present, e.g., the tabletop, the Vicon cameras and several computers. Additionally, the setting of the system is very sensitive concerning disruption. Furthermore we wanted to point a camera on the tabletop surface to record the user's behavior while interacting with the tangibles.

Need for consistent setting

Therefore we conducted our study in the laboratory. On this occasion we reserved the room "Project Space 2", that belongs to the [Media Computing Group at the RWTH](#)

[Aachen University](#)<sup>1</sup> In order to guarantee an overall consistent setup for the users, we reserved the room for the testing period of three days. At the same time we ensured that no one was allowed to enter the room while the user test was running by attaching a sign on the door.

## 5.2 Challenges

Conducting a study with the format, that we described in the previous section 5.1—“Format” is not easy to control. Several variables can influence the process of interaction and therefore affect the evaluation results. This chapter describes the discovered challenges and the way we faced them.

The environment has to be controlled

### 5.2.1 Awareness of Test Situation

The complete test environment consisted of a tabletop, a video camera and a Vicon. In addition, the study took place inside a room belonging to a university building. Therefore, there was no way to avoid the fact, that participants were aware of taking part in a test. This may have influenced the users’ behavior and their attitudes. There was no way of avoiding the awareness of a test situation. But we tried to minimize the uncomfortable perception of being in a controlled environment.

University room full of hardware leads to discomfort

Candy and soft drinks were provided and we encouraged the user to feel free to help himself. The participants were allowed to drink and eat between each task. So we tried to achieve a more pleasant atmosphere.

Provided candies and soft drinks

However, providing candies does not help, if a participant feels stressed by thinking of being in competition situation or anxious about making mistakes. For that reason we made clear that the importance lies just in executing the task without judging error rate, performance, or success.

Minimize competitive feeling

<sup>1</sup> <http://hci.rwth-aachen.de/>

We stated that not the successful task execution is of particular interest but all the ways how a user tries to fulfill the task.

Offered to deactivate video recording

In case that some users felt uncomfortable being filmed while executing the tasks, we tried to remedy. First, we offered them not to record their actions. Second, we even offered them to remove the camera setting completely. Even if a participant was not concerned about being filmed we additionally guaranteed him privacy.

### 5.2.2 Awareness of Wizard of Oz

Mouse clicks and presence of evaluator might reveal wizard

Using the Wizard of Oz principles is useful if resources are limited. Unfortunately the approach leads to problems in case that participants are aware of the wizard. The realization of not interacting with a remote partner but with someone who operates a software might have effects on the evaluation results. Several aspect could reveal the presence of a wizard. The evaluator operates a software for triggering shared objects on the surface by using a mouse. The problems is, that mouse clicks are audible and so a participant could be capable of recognizing a causal connection between the movement of actuated tangibles and a mouse click. Since the evaluator and the wizard are the same person and in the same environment a causal connection between body movements and actuated tangible might reveal the wizard as well.

Usage of touch input device instead of mouse

To avoid the audible information from a mouse click, we decided to change the input device. Instead of a mouse we used a [Magic Trackpad](http://www.apple.com/magictrackpad)<sup>2</sup> developed by [Apple](http://www.apple.com)<sup>3</sup>. Since the input device supports multitouch input, the clicks are no longer audible.

Sitting behind monitor hides movements

To avoid that a participant recognize a causal connection between body movement and actuation process we setup the interior of the room accordingly. The evaluator sits in front of a monitor and the back of the monitor points to the

<sup>2</sup>Apple Magic Trackpad: <http://www.apple.com/magictrackpad>

<sup>3</sup>Apple Inc.: <http://www.apple.com>



tabletop and the participants. In this way, the monitor for the most part hides the body of the wizard.

Although we tried to minimize the chance of revealing the presence of the wizard, there is no chance to exclude the revelation. For that, we asked the user after executing the tasks if they had the feeling someone else simulate appropriate output. In case that a user confirmed the questions, we asked him if he would act differently, and we noted that information in the discussion phase.

Consider revealing in  
result discussion

## 5.3 Setup

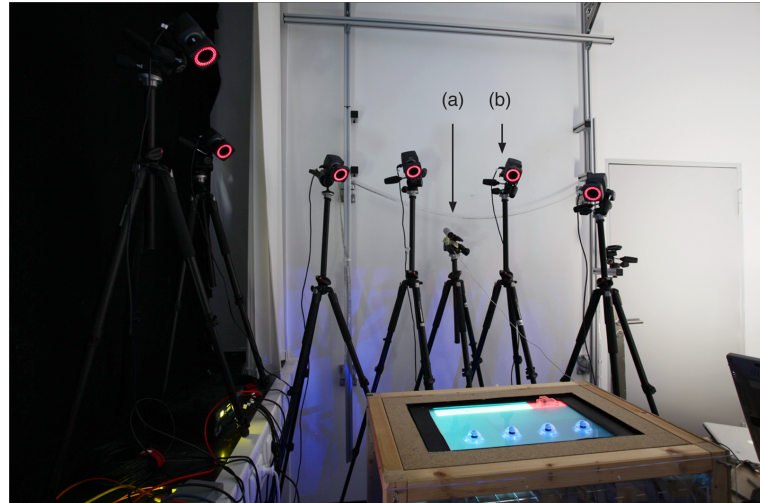
### 5.3.1 Environment

As mentioned earlier, the study was conducted in a small room belonging to the university and has a size of about 4 x 4 meters. We booked the space for a period of three days. Because of the need for an optimal tracking, each window was darkened by an opaque curtain. For video recording a lamp served as source of light. Unfortunately, the temperature in the room increased through the black curtain and the running hardware. Two participants complained about that fact. Within the room, only two persons are located. The participant who executes the task and the evaluator who accompanies the user while executing the tasks.

Small, dark, warm  
room

The tabletop was placed almost in the center of the room. Around the tabletop six Vicon cameras (figure 5.1.b) were positioned. Between the Vicon cameras a further video camera (figure 5.1.a) was mounted. For recording, we used a simple iSight camera developed by Apple. Although the video quality is not perfect we decided to use the iSight camera, since it additionally includes a microphone. So we were able to record the comments of the participants as well.

Tabletop, Vicon  
camera, iSight  
camera



**Figure 5.1:** The user test environment. **(a)** iSight camera. **(b)** Vicon camera.

### 5.3.2 Participants

5 females, 9 males

The study was conducted with 12 participants. 10 participants ranged from 21 to 35 years and consisted of 4 females and 6 males. The 2 remaining participants were in the age group of 50 to 60.

Recruitment through personal contact

We were looking for a mixture of participants. At first, we intended to collect participants by writing a circular. Then, because of unsatisfactory experiences with finding users in this way and afraid of only getting response from computer scientists, we decided to contact potential participants more personally. We used several methods. Some friends were contacted by telephone, others via personal mail and other by asking them on the fly.

Mixture of employed participants

The scheduling of appointments was a little complicated, since the study took place in midweek. After 1 week of coordinating dates we gathered the following participants: 2 interior designers, 1 psychology student, 6 computer scientist, 1 history teacher, 1 German teacher and 1 business studies student.

Few participants with background

The participants were asked to answer a self-assessment

form (appendix A—“Declaration of consent”) concerning their experience with tabletops, with passive TUIs on tabletops, and with active TUIs on tabletops. The selectable options were ranged from never, seldom, sometimes and frequently. All subjects were average computer users, two subjects had experienced tangible user interfaces. None of the users were familiar with actuated tangibles.

### 5.3.3 Test Procedure

The complete user test consisted of six test units, in each of which a participant executed five sorting tasks one after the other. Therefore, the total number of sorting tasks amounted to 30. Each test unit differed from the previous one in the type of provided user support.

Six test units, each with five sorting tasks

In the first four units we test the different kinds of visual support without the ability to disable or enable the actuation technology. In the last two test units each participant is allowed to use the tangible switch to disable or enable the actuation technology. Furthermore, each participant is asked to choose his favorite visual support method for the last test unit. An overview of the test procedure is pointed out in table 5.1—“User test procedure”.

Test units differ in user support

Test Unit	Task Repetitions	Visual Support	Interruption Support
1	5	None	No
2	5	Halo	No
3	5	Feedback	No
4	5	Feedforward	No
5	5	None	Yes
6	5	Free choice	Yes

**Table 5.1:** User test procedure

We chose five sorting tasks in each unit for certain reasons. One goal of this study was to evaluate different support methods. For that reason, we wanted to enforce several conflicting situations, while a participant executes the sorting task in coordination with a remote communication partner. In order to make sure that within each test unit occurs

Enforcing situations

the same conflicting situations, the sorting tasks were repeated five times. In this way, we wanted to learn how users respond to actuated tangibles in comparison to different kinds of user support.

Influencing task execution

In each task, the two collaborating users have to coordinate their actions. Nevertheless, problems will occur caused by different approaches to solve the sorting task. Based on what we learned from the related work and the initial survey, we focused on two appearances of distributed collaboration: helping and annoying. Table 5.2—“User test situations ” presents an overview of identified collaboration situations. In each test unit, the remote communication partner is introduced to enforce the listed situations consecutively.

Wizard helps or annoys user

Since no second table was available, a wizard (section 4.3.3—“Wizard of Oz”) actuated single tokens. The list of actions existed, that described his duties. Since the user interactions are not foreseeable, there was no way of guarantee a fixed order of actions. In fact the wizard decided in depending on the situation if he helps or annoys the participant. Three kinds to helping techniques were used: No influence, positioning an own pucks, helping the participant to position a token. Three ways to annoy the participants were defined: Undo the positioning, false positioning, hinder positioning.

Type of Situations	Situation
Helping	Remote user does not influence participant
Helping	Remote user positions own puck
Helping	Remote user helps participant by positioning a puck
Annoying	Undo positioning
Annoying	False positioning
Annoying	Hinder Positioning

**Table 5.2:** User test situations

### 5.3.4 Preparation of User

Greeting, Explaining, Consenting

After the participant entered the room, we nicely welcomed him. At first, we explained to him the purpose of the study

and what we expected. Finally the environment was introduced and we explained each component and its purpose. To ensure that a participant had no doubts or concerns we encouraged him to raise a question. After he assured us, that he had understood and accepted the environment, we asked him to sign a consent form. The form ensures that the participant allows us to record his interaction and to analyze the results. In return we guaranteed privacy.

After the formalities were settled, we showed him the general face of the task. First we demonstrated by hand how the participant should handle a physical puck in order to avoid occlusion problems and how a puck is recognized by the tracking algorithm. Furthermore we showed him at which pace the user can move the physical puck. After about two minutes of interaction with the puck, a participant might be able to succeed.

Puck tracking  
demonstration

Since we wanted to ensure, that each participant was aware of the puck motions, we allowed the user to execute an example task, in which one tangible should be removed from its current position. The example task we implemented, always tried to actuate the puck back to its origin. In this way, each participant was shown the actuation of tangibles and what it felt like.

Puck motion  
demonstration

Finally , the design of the sorting task was presented. At first, task- specific aspects were described, e.g. the goal of the task, the amount of repetitions, the different conditions and the challenges. Afterwards we introduced the graphical elements displayed on the screen and the purpose of the physical tokens as well.

Demonstrating the  
sorting task

## 5.4 Hypothesis

Based on findings from the literature review and the initial study we postulated two hypotheses:

*H1: Visually augmenting an actuation process minimizes the perceived loss of control*

*H2: Providing a technique to interfere with an actuation process minimizes the perceived loss of control*

## 5.5 Results

### 5.5.1 Preparation

Awareness of wizard

One of the participants was aware of the existence of the wizard since somehow he knew that no second table exists. The question whether this knowledge had influenced his behavior with the remote communication partner was confirmed. Therefore we decided to exclude his data from the analysis of the results.

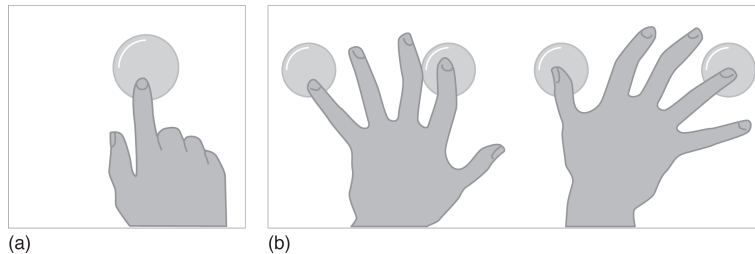
### 5.5.2 Video Observations

More aggressive behavior in the course of time

In the course of the test procedure an increased aggressive and demanding behavior regarding the remote communication partner became apparent. In the beginning the majority (8/11) of the subjects behaved in a reserved way and observed the decisions of the remote partner more or less. Later the impression arose that participants either accept or interfere with the actions depending on recent actions of the remote users, e.g., helping or annoying. On the other hand the remaining users behaved quite cautiously throughout the entire period of time and accepted the decisions of the remote user in most cases.

Pinning a puck to the surface

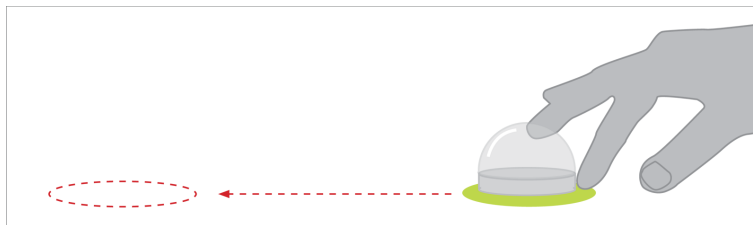
Throughout the entire task procedure the participants executed a variety of hand gestures to manipulate the pucks. To constrain the puck motion, all subjects pinned an object to the tabletop surface (figure 5.2.a). In four situations two subjects pinned several objects at once to the surface (figure 5.2.b). The behavior was discovered after the participants placed the pucks in the particular order. From observing the video recordings it seemed that the users protected their setup in answer to recent negative experiences with the remote user.



**Figure 5.2:** Pinning a puck to the surface. **(a)** Pinning one puck to the surface. **(b)** Pinning several pucks to the surface.

In several situations the puck motion suffered from a disadvantageous position on the surface regarding the electromagnetic fields. The consequence was that the motion velocity decreased significantly and the movement time increased accordingly. While some participants ignored that fact and waited, others (6/11) used the index finger to push the puck in the anticipated movement direction. From an observer point of view it seemed that the participants wanted to give the puck a helping hand (figure 5.3).

Pushing a puck in an anticipated direction



**Figure 5.3:** Pushing a puck in an anticipated direction.

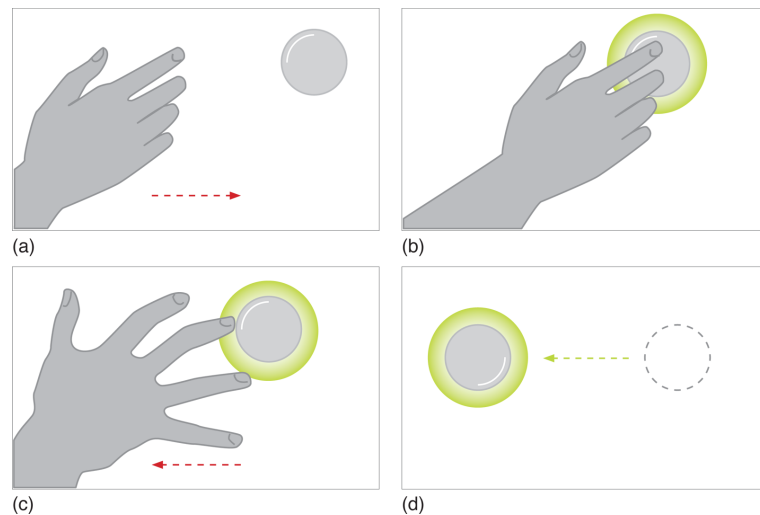
In case the intention of the remote partner was recognized as helpful, e.g., moving a wrongly positioned puck, the participants did not interfere in the majority of cases. In situations in which the actions of the remote partner apparently conflicted with the participant's idea, the corresponding person reacted. Almost all participants behaved to falsely positioned pucks of the remote user in the same way. In the beginning the participants observed the puck movement. As soon the movement stopped, the participants moved the puck to its old position. In case the remote partner

Reposition a puck again and again

responded similarly, the participant repeated his action as well. Two outgoings became apparent. A participant either gave up and ignored the incorrectly positioned puck or repositioned the puck until the remote partner resigned. To our surprise the participants were extremely persistent in the majority of cases .

Withdraw the hand  
from the puck

Once a future actuation was visually announced, the participants showed an interesting behavior. Assuming a participant intended to grasp at a puck and suddenly an information announces its upcoming actuation. As a reaction to the blinking information, the user withdrew his hand from the puck (figure 5.4). Such behavior was observed repeatedly in the majority of the participants (9/11).



**Figure 5.4:** Withdrawing the hand from the puck. **(a)** The user intends to grasp at a puck. **(b)** Suddenly an upcoming actuation is announced. **(c)** The user withdraws the hand from the puck. **(d)** The object moves to the designated coordinate.

No significant  
behavior when only  
showing initial point

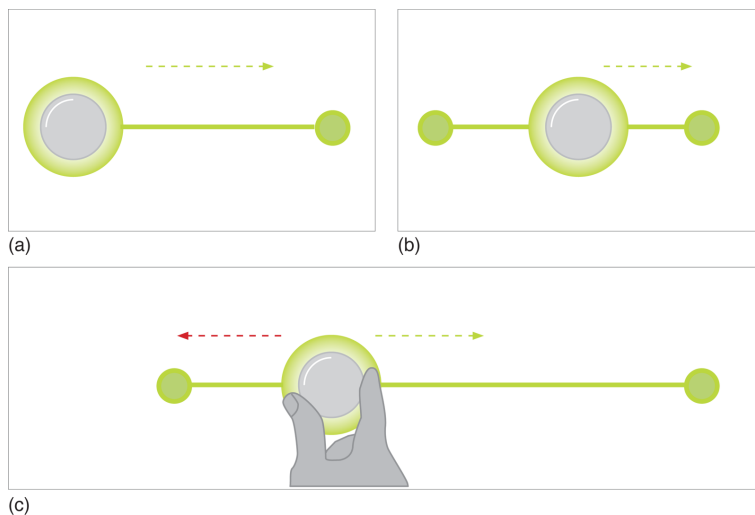
To our surprise no significant behavior was observed when visualizing the initial point of an actuated puck. The analysis of the video recordings yielded that all the participants more or less ignored the information. From the observer point of view, the knowledge regarding the past of an actuated tangible apparently does not provide an additional



value to the participants while executing the tasks.

In comparison to visualizing the initial point, the knowledge concerning the destination of an actuated puck revealed an interesting behavior pattern. Several participants (5/11) interfered with an actuated puck by pushing the object in the opposite movement direction (figure 5.5). Only in a few cases those participants placed and pinned the puck on its initial point. In the majority of the cases, the video recordings indicated that the participants tried to offer resistance to the remote communication partner. The behavior was recognized in situations where the anticipated goal of the remote partner conflicted apparently with the goal of the observed user.

Offer resistance by pushing a puck in the opposite direction

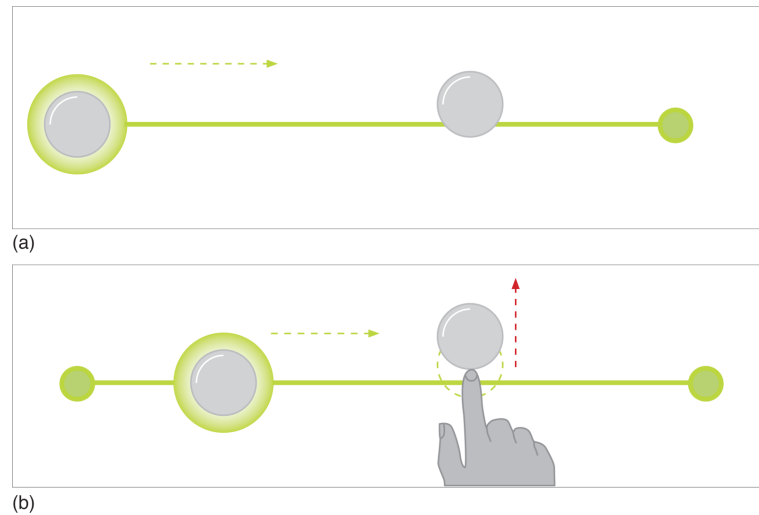


**Figure 5.5:** Offer resistance by pushing puck in opposite movement direction. **(a)** An upcoming actuation process is announced. **(b)** The puck currently moves to the destination point. **(c)** A participant pushes the puck in the opposite movement direction.

Another behavior pattern was recognized only when visualizing the movement path along with the destination point. The moment the movement path is visible a participant is able to anticipate a potential collision with a puck that is located on the path. Several subjects (3/11) tried to avoid such a collision. Repeatedly those participants

Pushing puck aside the movement path to avoid collision

pushed the puck that was located on the movement path aside in order to avoid a collision with the actuated puck (figure 5.6).



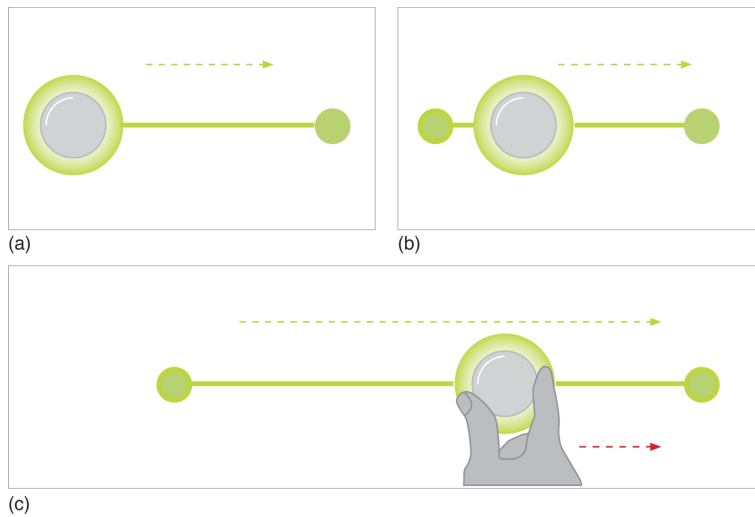
**Figure 5.6:** Avoid collision by pushing puck out of the movement path. **(a)** The destination point and movement path of a puck is displayed. **(b)** The participant pushes the conflicting puck out of the movement path.

Leading puck along movement path

Furthermore the video showed participants (6/11) that used the visualized movement path in a different way. As soon as the destination was visible those participants repeatedly led the puck along the movement path to the destination point (figure 5.7).

Aggressive use of switch

An increased aggressive user behavior was discovered when activating the tangible switch. When the users were allowed to use the switch, we observed an increased demand to control the pucks. All subjects made use of the interruption technique, where the usage differed by frequency, time and purpose. Few participants (3/11) used the switch as soon as the task started. The consequence was that no collaboration took place during the tasks. Other participants (7/11) at least tried to perform the sorting task in coordination with the remote communication partner. Once a participant sensed a first sign of incorrect behavior, the switch was operated immediately. The videos showed



**Figure 5.7:** Leading a puck along the movement path. **(a)** An upcoming actuation process is announced. **(b)** The puck currently moves to the destination point. **(c)** The participant leads the puck along the movement path to the destination.

no signs of offering resistance or pinning a puck on the tabletop surface before using the switch.

By observing the video recordings, we uniformly received the impression that each peripheral puck movement draw the attention of the user. The participants either paused their performance for a short time or completely stopped the task execution until the puck movement seemed to have come to an end. Three participants were distracted repeatedly in a way, so that they forgot the designated target order. The consequence was that they waited until the remote partner took over.

All the participants were asked to choose a visual support technique of their choice. The majority decided to use the visualization of the movement path along the destination point. Only one participant selected the visual support technique, that visualized the initial point of an actuated tangible.

Moved pucks distract the participants

Visualizing destination point was selected most frequently

The table 5.3—“Summary of observed behavior from video recordings” provides an overview of the observed behavior.

	Observations
1	Generally a more aggressive behavior in the course of the time
2	Pinning a puck to the surface
3	Reposition a puck again and again
4	Withdrawal the hand from a puck when announcing actuation
5	No significant behavior when only showing starting point
6	Offer resistance by pushing puck in opposite direction
7	Push puck aside visible movement path to avoid collision
8	Lead puck along movement path
9	Offer resistance by pushing puck in opposite direction
10	Aggressive use of switch
11	Distraction through puck movements
12	Frequently selected visual support was showing the target point

**Table 5.3:** Summary of observed behavior from video recordings

### 5.5.3 Speaking Aloud

Few collected data

Repeatedly we encouraged the participants to raise concerns or impressions but without great success. Only after asking the participants to speak aloud they expressed statements. Unfortunately, the procedure endured not very long. To avoid to put a participant off his stride the amount of encouragements was limited to three. For that reason, this data acquiring technique yielded a limited number of subjective data. The majority of the data was basically collected in the beginning of each test procedure. Nevertheless, the data provided an interesting insight into subjective impressions.

Desire to communicate with remote partner

Several participants expressed the desire to communicate directly with the remote user. The motivation of communicating directly had two reasons. First, three participants recognized repeatedly an incorrect behavior. Therefore, they had the desire to inform the remote user accordingly. One of the participants uttered “I am going crazy if he does not stop doing this” in answer to a repeatedly repositioned

puck. Second, three participants expressed uniformly the desire to communicate with the remote partner in order to coordinate the access to the shared tangibles.

Within the first test unit, in which no support was provided five participants complained about the sudden movements of the pucks. All participants expressed the desire to see an actuation process in advance. “When I could recognize a future movement I would be able to prepare myself” mentioned one participant. Another one suggested that he “would find it useful if the remote user could show me his intentions with a puck in advance” in order to coordinate the collaboration. Later, the same person commented “Ah, that is helpful, now I can concentrate on the remaining pucks” in reaction to the visible movement path along with the destination point of the actuated puck.

Desire to recognize  
upcoming actuation

The majority of the participants made comments that provided insight into their emotional state. In several situations they complained about the automatic behavior of the puck or the behavior of the remote users respectively. One participant whispered “bad other user”, in answer to a positioned puck that suddenly moved to another position on the table. Another one uttered aggressively “I would like to punch him if he does that again” in answer to a repeatedly incorrectly positioned puck. The moment a puck behaved unexpectedly, seven other participants showed repeatedly signs of frustration or anger accompanied by a curse. Example expressions are “Hey!”, “What is your problem?”, “Damn You!”, “You are so dumb. That annoys me”.

Emotional comments

The table 5.4—“Overview of the findings from the comments while executing the task” summarizes the findings.

	Findings
1	Desire to communicate directly
2	Desire to anticipate behavior of remote partner
3	Curses and emotions

**Table 5.4:** Overview of the findings from the comments while executing the task

#### 5.5.4 Retrospective Interviews

Recent behavior of remote partner influenced participants

In the course of the test procedure an increased demanding behavior was observed regarding the actuated puck or the remote user respectively. Therefore the question was posed that addressed their motivation. The majority of the participants (7/11) argued that depending on the recent actions of the remote partner their own behavior changed. "Since I thought the remote user annoys me purposely" one interviewee confirmed, he wanted to "restrict his degree of freedom". Another interviewee admitted that "In case I was sure regarding the designated target order I tried to protect the setup definitely" in answer to "recent negative experiences" with the remote partner. For that reason, three participants recommended the existence of the switch to enable or disable the actuation technology. In this way, "I am able to switch off the remote partner" admitted one of them.

Communicating via reposition puck again and again

Several participants repositioned a puck again and again in answer to a moved object of the remote partner. Some behaved very persistently until the remote partner resigned. Asking the corresponding participants concerning the purpose yielded an interesting intention. Obviously each participant thought that the other user was wrong regarding the designated order. For that reason, the subjects used reposition gesture as a result of the missing possibility to communicate directly. In this way "I wanted to inform the user that he is wrong" and that he "please should resign to reposition my puck". Another one argued with "my persistence should tell him that I have a different meaning regarding his recent action". A less persistent participant confirmed that he "tried to convince the remote partner" but soon he "was frustrated and gave up".

Communicate via offering resistance

While executing the tasks, the evaluator observed that participants intended to offer resistance against the remote partner. A puck was pushed repeatedly in the opposite movement direction. Therefore the question was posed regarding the anticipated goals. Few participants (3/11) answered that they saw the movements path as kind of "rubber band" and intended to try their strength with the remote partner until the band will rip. Another subject an-

swered “I did not accept his actions” so I offered resistance in order to inform the remote partner that “I think different” regarding his recent behavior. Similarly, two interviewees argued that they applied the gesture as means of communication since no other way to communicate with the remote partner was available.

The question whether the participants perceived an increased control while providing the support techniques was confirmed in the majority of cases. Especially two aspects impact their perception of control. First, the knowledge about the motivation of the other user by seeing the movement path was helping. “When I was aware of the motivation of the remote user, I accepted the automatic behavior of the tangibles” stated one participant but “the moment I had to guess the motive I felt helpless”. Second, the ability to operate the switch in order to turn off the actuation technology was considered as extremely powerful and recommendable. Apparently the participant understood the switch to turn off the remote user instead of disabling the actuation technology.

More control  
because of switch  
and visual support

Each participant was asked regarding his selected visual support variant. As mentioned in the 5.5.2—“Video Observations”, the majority of the participants recommended the visualization of the target point along the movement path. They uniformly argued that in contrast to the other visual support techniques this one was really helpful for coordinating the own actions with the ones of the remote partner. For example one participant mentioned that he was able to “plan his own actions” and it increased the feeling of actual working together. Two others stated that in this way it was additionally easier to accept the automatic behavior of a puck, since they knew the anticipated destination. For example one of the two described that “the moment I see the destination of a puck movement I just let go and switch the focus on another puck”.

Target point of an  
actuation helped the  
most

The table 5.5—“Overview of the findings from the retrospective interviews” summarizes the findings.

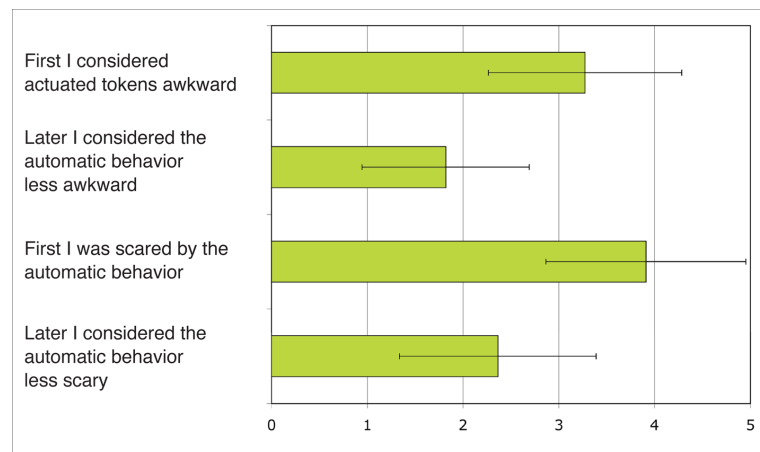
	Findings
1	Recent behavior of remote partner influences participants behavior
2	Communication via reposition puck repeatedly
3	Communication via offering resistance
4	Support technique increases partially the sensation of control
5	Seeing the target point increases sensation of actually collaborating

**Table 5.5:** Overview of the findings from the retrospective interviews

### 5.5.5 Questionnaires

User get used to the automatic behavior

The comparison of the mean values of Q1 and Q2 indicates that the participants considered the automatic behavior of the actuated tangibles less awkward in the course of time (figure 5.8). The comparison of the mean values of Q3 and Q4 suggests that the automatic behavior of the actuated tangibles is less scaring the longer the participants are interacting with them (figure 5.8). Although the rating results do not tell whether the findings depend on the learning curve or the provided support techniques, we assume that users are getting used to the automatic behavior of actuated tangibles. Several participants of the brainstorming session doubt that fact.



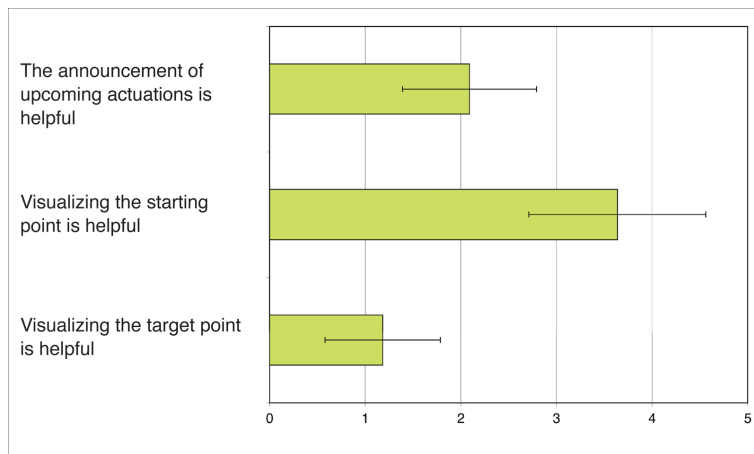
**Figure 5.8:** Actuation experience ratings

Feedforward is very helpful

According to the low average rating of 1,18 (standard deviation(sd)=0,51) of Q7, the visualization of the movement



path along with the destination point can be considered as helpful when interacting with an actuated puck or a remote user respectively (figure 5.9). In contrast, the high average rating of 3,64 (sd=0,78) regarding the visualization of the initial point of an actuated tangible indicates that participants see only a small additional value when providing such information (figure 5.9). Furthermore, the average rating of 2,09 (sd=0,45) indicates that it is advantageous to announce a future actuation process (figure 5.9).



**Figure 5.9:** Visual support ratings

The majority of the participants (8/11) confirmed that the automatic token actuation did not distract (Q8) them. Three participants admitted that they were only distracted within the first test unit as a result of the surprise effect of a sudden movement. One of the users explained “after I was able to recognize a movement in advance, I tried to integrate the information into my workflow” and “ignored the peripheral movements”. The general impression of the users not being distracted by token actuations is slightly confusing since the video observations indicated the opposite.

Q8: Automatic behavior is distracting

Several participants (7/11) admitted that they were frustrated (Q9) as a result of the automatic behavior of the pucks or the remote user respectively. The corresponding statements indicate that in situations in which a participant felt safe regarding the sorting order and the remote user interfered, led to frustration. One participant confirmed that

Q9: Automatic behavior is frustrating

he felt frustrated when “I realized that the remote partner wrongly repositioned my puck but I did not interfere because I trusted him”. Comparing those results with the observations of the video recordings and especially with comments, the answers of the questionnaire underline the observations.

Q10: Visual support is distracting

The question (Q10) whether providing visual support is distracting was confirmed by only two participants. One participant complained that “the blinking effect lasted too long, so I waited and finally I forgot the target order”. The other participant confessed that he “often switched the focus and forget the target order sometimes” when visual support appeared. The remaining participants (9/11) uniformly stated that they were not distracted by visual support. One of them admitted that in the beginning he had to get used to the visual support but soon “accepted the visualizations as a pleasant support” while executing the tasks in coordination with a remote communication partner.

Q11: The switch is helpful

All participants confirmed the question that the existence of the switch to enable or disable the actuation technology is helpful (Q11). “It gave me the feeling of being in control, I think it is useful for people who are disturbed by the movement or who cannot concentrate” was mentioned from one user. Further participants pointed out that they used the switch in response to recent behavior of the remote user. In this way “I can disable my partner in case he makes repeatedly mistakes” and furthermore “I do not have to wait for my slowly working partner”. Since “I was not able to communicate directly with my partner” one participated argued, “I used the switch to tell him that he was wrong”.

Q12: Constant existence of switch is desired

On the other hand all participants (11/11) negated the question whether a technique to enable or disable actuation technology should always be available (Q12). In general, the participants identified a conflict in case of two subjects block each other. For that reason some suggestions were proposed how to improve the technique. For example, one user argued to “only allow to enable or disable one single puck”, so that a remote partner is allowed to proceed with a different tangible. Two other participants recommended the general idea but were worried at the same time. The amount of control should depend on the degree of the re-

remote communication partner. In case the remote partner is some kind of a follower, the ability to enable or disable the actuation technology should be restricted.

All participants agreed the statement whether the visual support had influenced their behavior (Q13). "In some situations I just waited until the remote partner had finished his actions" was mentioned two times. Furthermore, two other participants described it as helpful to know in advance which puck starts to move, so they decided to switch their focus to another puck that needed to be positioned. One user admitted that in some situations he became uncertain in answer to the visualisation. Hence, he passed the control to the remote partner and hoped that he remembers the correct sorting order.

Q13: The visual support had influenced my behavior

All participants (11/11) confirmed the question that the possibility to enable or disable the remote user had influenced their general behavior with the remote user (Q14). "If the user recently acted strangely, I directly used the switch" argued one participant and complemented with "unfortunately I had felt a little bit sorry because I had excluded him from collaboration". Another user commented that he in fact did not want to use the switch because of "someone excluding is not collaborative" but as he had the impression that he wants to annoy him, he wanted to take the initiative and gain control. His intention was to show the remote user on this way to act more cautious in the future.

Q14: The switch influenced my behavior

Similar to what was revealed from the other data sources, the majority (10/11) of the participants found the announcement of the target point the most helpful (Q15). One participant described that in this way he could compare his intention more easily with the intention of the remote partner before the actuation process was actually happening. So "it is easier to coordinate the actions with the remote user". Two other participants argued that having the ability to see the movement paths makes it possible to use a different path for avoiding a collision. Another user admitted that recognizing the destination of an actuated puck enabled him to anticipate the goal of the remote partner. The consequence was that he was "able to help him by removing the pucks located along the intended movement paths". Furthermore, six participants affirmed an increased sensa-

Q15: Most helpful visual support

tion of actually collaborating when seeing the intentions of the remote partner.

Q16: Less helpful  
visual support

The sole announcement of an upcoming actuation was considered as less helpful (Q16) from four participants. Those people argued that it had no influence on their behavior with the remote partner. Apparently, the reason was that the single halo delivers too little information. In contrast, the remaining participants argued that the information about the initial point was less helpful. The majority explained their decision with the limited space on the tabletop. “The task was too easy and I always knew the initial state of an object” wrote one user. Another participant stated that the knowledge of the starting point “provided no additional value regarding the scenario”. At the same time those participants assumed that such kind of information could be useful when working on a bigger table equipped with more than four tangible objects.

Further remarks

Several participant left further remarks. One participant considered the audible noise of actuated pucks as important. “In this way I am informed regarding actuation process without looking at them directly”. Another user expressed the desire to “exchange thoughts” to avoid to work against each other. “I would appreciate a mechanism to communicate wrong behavior” stated a further participant.

## 5.6 Conclusion

This thesis proposes and evaluates two techniques to minimize the loss of control. The section presents the conclusions regarding our hypothesis *H1* and *H2* based on the collected data of a qualitative study.

### 5.6.1 Hypothesis *H1*

Visual support  
decreases loss of  
control

Several types of visual support were evaluated. The results of the collected data indicate that the presented techniques more or less support the users while interacting

with actuated tangibles or a remote communication partner respectively. Especially the knowledge concerning the target point along with the movement path seemed to be a promising approach. In this way the participants confirmed that they were able to recognize the intention of the remote partner more easily and behaved accordingly. In contrary, visualizing the initial point of an actuated tangible apparently provided no additional value. Nevertheless, we argue that the results of this study support the hypothesis *H1*. The assumption is emphasized by the fact that providing visual support apparently barely distracted the participants.

### 5.6.2 Hypothesis *H2*

The video recordings showed that users frequently operated the switch to disable the actuation technology to perform the tasks. The results of the interviews and the questionnaires finally revealed that the participants operated the switch since they wanted turn off the remote users in order to gain exclusively access to the shared objects. Their decision based on recent negative experience with the remote partner. From that point of view, the observations support the hypothesis *H2*. On the other side all participants raised concerns regarding the switch in the context of realistic working environments. In generally the subjects recommend a technique to interfere with the remote partner. But according to the participants our proposed technique is too drastically and might lead to further problems. Since all communication partners have the ability to operate the switch a mutual exclusion is likely. We realize that our proposed technique to interfere with an actuation process is not applicable for realistic collaborative distributed working environments. Nevertheless, the observed behavior of the participants and the suggestions how to improve the technique to interfere with the remote partner indicate the importance of such technique. We argue that the findings from the study in general support the hypothesis *H2*.

Interfere technique  
partially decreases  
loss of control

### 5.6.3 Significant Observations

Desire for  
communicating  
directly

Comments and interviews revealed that several participants have a desire to communicate directly with the remote partner. The purpose was to coordinate the access to the shared resources. Our environment did not provided such technique. Therefore the participants tried to remedy. Some subjects pushed a puck in the opposite movement direction to offer resistance while other reposition a moved puck by the remote user again and again. In this way they intended to communicate with the remote partner. Apparently communicating directly could be another possible way to interfere with the behavior of the remote partner and minimize the loss of control.

## Chapter 6

# Summary and Future Work

### 6.1 Summary and Contributions

The thesis addresses the problem of reduced control in the context of actuated tangibles on tabletops. In a tabletop environment with actuated tangibles, the system is able to change the position or the state of inner agile parts of tangibles automatically. In this way the consistency between the tangible and the digital world can be guaranteed. The consequence is that occasionally a user has only partial control regarding the physical environment and may experience a loss of control. This thesis explores how users experience the automatic behavior and evaluates techniques that we have designed to reduce the sensation of a loss of control.

Motivation

Chapter 2—“Related Work” describes how projects in the field of actuated tangibles on tabletops influenced the development of this thesis. The review showed that no study addresses directly the problem of reduced control and an understanding of the characteristics of control and the consequences of a loss of control is missing. We concluded, that designing methods to minimize the loss of control, a better understanding of control is necessary. However, some results from the review procedure provided first ideas how to minimize the loss of control, e.g. visually announcing up-

Related work

coming actuations or allow the user to disable the actuation technology for a period of time.

#### Initial study

Chapter 3—“Initial Study” illustrates our approach to understand the term control and its characteristics. To understand the cause and consequences of control, we decided to explore psychology literature on human-human interaction. The purpose was to borrow psychological theories regarding user control and adapt those theories to the field of human-computer interaction with focus on actuated tangible user interfaces on tabletops. From studying psychology literature we concluded that in general a user feels a loss of control when he is not able to influence, explain or predict events or their outcomes. For defining a context-dependent understanding of the term user control, a brainstorming session was conducted. In the brainstorming session, we proposed an imaginary scenario, in which each participant sorts a set of shared tangible objects in coordination with a remote communication partner. Finally, we asked the participants to identify conflicts of situation, that would impact their perception of control. The analysis of the statements indicates, that users have a desire to see an upcoming actuation in advance, the destination of an actuated object or to be allowed to avoid an upcoming actuation process. Based on those findings we decided to design corresponding support technique in the hope to minimize the user’s sensation of a loss of control.

#### System and task design

Chapter 4—“System Design” describes the tabletop environment in which we conducted the user study. In addition, this chapter illustrates the design decision for the user tasks based on the findings from the initial study. Due to several software and hardware restrictions, this chapter furthermore explains our procedures to overcome those restrictions. For example, the tracking technique of our tabletop system is slightly unstable and sensitive to ambient light. Therefore we decided to track tangibles objects on the surface by using the Vicon tracking system and to adapt the tracking algorithm accordingly. For the purpose of the study we constructed a new set of tangibles: a hemispherical puck and a switch. After the modified system was able to track and actuate our tangibles on the surface, we finally designed and implemented the user task and different support techniques. Participants are asked to place



a set of shared tangibles in a particular order in coordination with a remote communication partner. Since a second table was unavailable, we simulated the existence of the remote communication partner. For that reason we applied the Wizard of Oz approach in which the wizard simulates the responses of the remote partner and enforces conflicting situations. A implemented software served the wizard as tool to simulate the remote user by operating a graphical user interface with a mouse input device.

Chapter 5—“User Study” finally evaluates the user behavior by observing video recordings and analyzing retrospective interviews and questionnaires. The complete user test consisted of six test units, in each of which a participant executes five sorting tasks one after the other. Therefore, the total number of sorting tasks amounted to 30. Each test unit differs from the previous one in the type of provided user support. The analysis of the data yielded that providing adequate visual support apparently increases the sensation of control. Especially the technique to show the target point along with the movement path of an actuated tangible seemed to be a promising approach. In this way the majority of the participants were able to recognize the intention and the anticipated goals of the remote partner and behaved accordingly. We realized that the proposed interference technique is not usable for practical working environments. Nevertheless the majority of the participants recommended such technique and proposed less aggressive approaches for future work. Furthermore the participants expressed a desire to communicate directly with the remote partner. Since no such technique was available the participants tried to remedy. Some subjects pushed a puck in the opposite movement direction to offer resistance while other reposition a moved puck by the remote user again and again. The purpose was that in this way the participant intended to communicate with the remote partner to tell him that he behaves incorrectly.

Evaluation of user  
study

## 6.2 Future Work

Testing in a less observing environment

The study took place in a lab environment consisting of several cameras and computers. There was no possibility to avoid the fact that participants were aware of attending a test. The consequence is that the awareness of being in a test situation may influence the users' behavior and distort the evaluation results. Although we tried to make the environment as much comfortable as possible, several participants commented that they probably would behave differently in a less observing environment. Therefore we suggest to repeat a similar test, when the corresponding technology is mature and flexible enough to be tested in the field.

Testing a more realistic scenario

Instead of evaluating a simple puck sorting scenario, we propose to design a more realistic scenario for future user studies. In the retrospective interviews, several participants argued that they had problems to understand why two users should place a set of tangibles in a specific order. We assume that identifying with a scenario will yield more valuable data compared to the puck sorting scenario.

Testing on a bigger table

From the retrospective interviews and the questionnaires we discovered that the majority of participants found the visualization of the initial point of an actuated puck useless. They argued that the tabletop was too small to receive an additional value from that kind of information. At the same time those users could imagine an additional value, when the tabletop surface was bigger and more than only four tangibles were located on the surface. For that reason, we propose to conduct future tests on tabletops with bigger surfaces.

Real collaborating on two tabletops

Due to financial and time limitations only one tabletop was available. For that reason, a wizard simulated the actions of the remote communication partner. Although the wizard fulfilled its task and enforced conflicting situations, we recognized some drawbacks. In many situations the participants acted very quickly. The consequence was that the wizard occasionally wasn't able to react appropriately because of the mouse movement time. We assume a real remote communication partner would not have that problem

and could respond more easily to the user's actions. We propose for future work to actually observe two spatially separated participants while sharing tangibles and coordinating their actions.

This study mainly actuated pucks on a surface in order to achieve a particular target order. But several other actuation processes are possible, e.g. rotating agile parts of a knob. From our collected data we observed that in the few situations the switch was actuated, we observed that every participant jerked. Another study should evaluate how users respond to actuation process of more complex tangibles.

Evaluating more complex tangibles

Several participants of our user study desired a direct way to communicate with the remote communication partner. The desire was raised either as a comment while executing the sorting task or as a written statement in the questionnaire. We discovered the same suggestion in the brainstorming session. We rejected this support technique, since we wanted to avoid that the task execution suffers from language skills. But the repeated desire to communicate directly seemed important in order to coordinate the access to the shared object. Therefore one idea for future work could be to provide a communication channel, instead of a technique to enable or disable the actuation technology.

Providing communication support



## **Appendix A**

### **Declaration of consent**

## EINVERSTÄNDNISERKLÄRUNG

Bitte lesen Sie sich die nachfolgende Erklärung sorgfältig durch und füllen Sie bei Einverständnis den Teilnehmersteckbrief unten aus.

### KONTEXT DES BENUTZERTESTES

Diese Studie findet im Rahmen meiner Diplomarbeit an der RWTH Aachen statt.  
In der Studie wird das Benutzerverhalten im Umgang mit TUIs auf einer interaktiven Oberfläche getestet.

### ABLAUF:

Die Teilnahme der Studie besteht aus unterschiedlichen Test in denen Sortierungsaufgaben in verschiedenen Varianten durchgeführt werden sollen. Diese Studie sollte etwa 45 Minuten dauern.  
Nach der Studie wird ein Fragebogen ausgegeben in dem Fragen zum getesteten System auszufüllen sind.  
Das Ausfüllen geschieht auf freiwilliger Basis, d.h. Sie können selbst entscheiden welche Fragen Sie beantworten möchten und welche nicht.

### ALTERNATIVE ZUR TEILNAHME

Die Teilnahme an den Tests ist freiwillig . Es steht Ihnen frei Ihre Teilnahme zurück zu ziehen oder abbrechen.

### VERTRAULICHKEIT

Alle Informationen, die während der Studienphase gesammelt werden, sind streng vertraulich. Ihre Daten werden nur durch Identifikationsnummern identifiziert. Sollten wir Zitate aus dem Fragebogen oder der Videoaufzeichnung in Berichten oder Präsentationen verwenden, so geschieht dies ohne Angabe Ihres Namens. Jegliche persönlichen Daten werden entweder verändert oder weggelassen.

Ich habe die Hinweise auf diesem Formular gelesen und verstanden.

Die Tests werden mit einer Videokamera aufgezeichnet.

Ich bin damit einverstanden, dass bei den Tests Videoaufnahmen von mir gemacht werden.

Geschlecht:

männlich  weiblich

Alter: \_\_\_\_\_

Beruf: \_\_\_\_\_

Ich habe schon an interaktiven Tischen gearbeitet?

nie  selten  gelegentlich  häufig

Ich habe schon mit Tangible User Interfaces auf interaktiven Tischen gearbeitet:

nie  selten  gelegentlich  häufig

Ich habe schon mit steuerbaren Tangible User Interfaces auf interaktiven Tischen gearbeitet:

nie  selten  gelegentlich  häufig

\_\_\_\_\_  
Datum / Unterschrift des Teilnehmers

Figure A.1: Declaration of Consent

## **Appendix B**

# **Questionnaire**

**Remark**

1. Actuation = Bringing an object to move

**General questions concerning actuation**

		1 = Completely agree			5 = Completely disagree	
<b>Question</b>		<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
Q 01	At the beginning I found an automatic token actuation awkward	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q 02	In the course of time I found an automatic actuation less awkward	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q 03	At the beginning I was scared by an automatic token actuation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q 04	In the course of time I was less scared by an automatic token actuation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q 05	The sole announcement of upcoming token actuation is helpful	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q 06	Visualizing the starting point of a token actuation is helpful	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q 07	Visualizing the target point of a token actuation is helpful	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Figure B.1:** Questionnaire part 1



Question	Yes	No
<b>General questions concerning actuation</b>		
Q 08	An automatic token actuation distracted me <input type="checkbox"/> <input type="checkbox"/>	
	In which situations? Why?	
Q 09	An automatic token actuation frustrated me <input type="checkbox"/> <input type="checkbox"/>	
	In which situations? Why?	
<b>Visual support</b>		
Q 10	Which of the visual support variants do you find the most helpfully?	
	Why?	
Q 11	Which of the visual support variants do you find unhelpful?	
	Why?	
Q 12	Visual support distracted me <input type="checkbox"/> <input type="checkbox"/>	
	In which situations? Why?	

Figure B.2: Questionnaire part 2

Question		Yes	No
<b>Interruption technique</b>			
Q 13	The existence of the switch to get control over the tokens is helpful	<input type="checkbox"/>	<input type="checkbox"/>
	Why?		
Q 14	Should the switch always be existent?	<input type="checkbox"/>	<input type="checkbox"/>
	In which situations? Why?		
<b>User Behaviour</b>			
Q 15	Visual support influenced my behaviour	<input type="checkbox"/>	<input type="checkbox"/>
	In which situation? Why?		
Q 16	The switch influenced my behaviour	<input type="checkbox"/>	<input type="checkbox"/>
	In which situations? Why?		

Figure B.3: Questionnaire part 3

Remarks

Figure B.4: Questionnaire part 4



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# Index

- abbrv ..... *see* abbreviation
- Actuated Workbench ..... 4, 10, 19
- Actuation ..... 48
- Actuation interference ..... 36
- ActuationFramework ..... 43, 48
- Augmented Coliseum ..... 11, 19
  
- Behavioral control ..... 25
- Brainstorming ..... 24, 28
- Brainstorming procedure ..... 28
  
- Cognitive control ..... 26
- Control ..... 4, 19, 24, 27
  
- Discrete Grid ..... 42
  
- Fiducial marker ..... 17, 44, 46
  
- Gradient marker ..... 15
- Graphical user interface ..... 11, 51, 58, 60
- GUI ..... 11
  
- Hardware connect button ..... 51
- Hypothesis ..... 71, 86
  
- Information control ..... 26
- Interrupt actuation process ..... 19
- introduction ..... 1–5
  
- Likert scale ..... 64
- Loss of control ..... 4, 25
  
- Mac OS X ..... 42
- Madgets ..... 4, 15, 19, 40
- Magnet Array Interface ..... 51
- Magnets view ..... 52, 60
- Manhattan Motion ..... 49
- Marker ..... 11
- Mechanical Constraints ..... 4, 14, 19, 35

---

Objective control .....	24
Participants .....	68, 70
Perceived control .....	24, 35
Power on button .....	52
Puck .....	10, 46, 55, 71
Qualitative study .....	20, 64
Questionnaire .....	64, 82
ReacTable .....	1
reactIVision .....	44
Remote Active Tangible Interactions .....	4, 13, 20
Remote user .....	20, 36
Retrospective control .....	26
Retrospective interviews .....	64, 80
Robot .....	11
SLAPFramework .....	42, 47
Sorting task .....	36
Speaking aloud .....	78
Subjective Control .....	24
Switch .....	46, 55
Tangible Bots .....	3, 17, 19
Tangible user interface .....	1, 41, 46
Task design .....	55
Test control .....	58
Test environment .....	64
Test procedure .....	69
Thinking aloud .....	64
Tracking .....	47
Trigger Magnets .....	52
Trigger magnets .....	61
Vicon .....	44, 67
Vicon connect button .....	52
Vicon marker .....	46
Vicon software .....	45
Video recordings .....	64, 72
Visual support .....	19, 35, 57
Within group evaluation .....	63
Wizard of Oz .....	59, 63, 66, 70

