RWTH AACHEN UNIVERSITY

PowerSocket

Implementation and Evaluation of an On-Socket Power Consumption Display

Bachelor's Thesis at the
Media Computing Group
Prof. Dr. Jan Borchers
Computer Science Department
RWTH Aachen University

by
Wolfgang Kluth

Thesis advisor:
Prof. Dr. Jan Borchers

Second examiner:
Prof. Dr. Stefan Kowalewski

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

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

Aachen, April 2011
Wolfgang Kluth

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Abstract

Due to the fact that we use more and more electrical devices, the demand of energy and electricity has grown significantly during the recent years. Consequently, we have to change our consumption behavior to reduce our power consumption. One step to this goal is an improved perception of consumed power. People do not realize how much energy they use daily, especially how much energy particular appliances consumes. This is an effect of missing feedback because energy is neither visible nor tangible. This is the reason why we have to increase the consciousness of home energy consumption of consumers.

After a survey about energy consumption in German households which showed us that most of the people are aware of their energy behavior and costs, we decided to create an ambient information system with direct feedback embedded directly into the socket. With a prototype displayed on an Apple iPad, we compared five different types of visualizations with the outcome that it is necessary to build a physical prototype to get significant findings.

PowerSocket is a power consumption display integrated into an electrical socket which maps the power consumption of a plugged-in device into a visualization on an ambient display. PowerSocket is composed of two units, the data- and the visualization-unit. It displays a rotating luminescent spot based on the measured data. The point of light rotates in a circular motion around the socket. Rotation speed and color are defined by the currently used power. Low energy consumption, e.g., 2 Watts, is visualized by a green light and a slow rotation (4 rpm), whereas with high energy consumption, e.g., 1000 Watts, the rotation is very fast (120 rpm) and the color turns to red.

Finally, we made a user study with eight subjects and tested the PowerSocket prototype in comparison with an ordinary personal energy meter. A lot of interest results which support our assumptions.

Überblick

Der Energie- und Elektrizitätsverbrauch stieg in den letzten Jahren signifikant an. Als Konsequenz müssen wir unser Konsumverhalten ändern, damit wir in Zukunft Energie sparen können. Ein Schritt in diese Richtung wäre die Wahrnehmung von Stromverbrauch zu verbessern. Man weiß heutzutage nicht, wie viel Energie man täglich benutzt, geschweige denn wie viel Strom einzelne Geräte verbrauchen. Dies liegt unter anderem am fehlenden Feedback, denn Strom ist weder fass- noch sichtbar. Aus diesem Grund muss man das Bewusstsein für Stromverbrauch stärken.

Nachdem wir eine Umfrage über Stromverbrauch in deutschen Haushalten durchgeführt haben und herausfanden, dass sich die meisten Menschen über ihr Energieverhalten und die Kosten im Klaren sind, entschieden wir uns dazu ein "ambient information system" mit direktem Feedback zu entwickeln, das direkt in die Steckdose integriert ist. Mit einem Prototypen, dargestellt auf einem Apple iPad, verglichen wir fünf Visualisierungstypen mit dem Fazit, dass es nötig ist einen Hardware Prototypen zu bauen um signifikante Daten zu erhalten.

PowerSocket ist eine in eine Steckdose integrierte Stromverbrauchsanzeige, die den aktuellen Stromverbrauch des angeschlossenen Gerätes auf einem Display anzeigt. PowerSocket besteht aus zwei Teilen, einem Daten- und einem Visualisierungs-Gerät. Es zeigt abhängig vom Stromverbrauch einen um die Steckdose rotierenden Lichtpunkt. Drehgeschwindigkeit und Farbe werden durch den aktuellen Stromverbrauch definiert. Wenig Stromverbrauch, z.B. 2 Watt, wird mit grünem Licht und langsamen Umdrehungen angezeigt, während viel Stromverbrauch, z.B. 1000 Watt, mit schnellen Umdrehungen und rotem Licht angezeigt wird.

Als letztes haben wir in einer Benutzerstudie mit acht Probanden unseren Hardware-Prototypen gegenüber einem normalen Strommessgerät für die Steckdose getestet. Dabei erhielten wir sehr aufschlussreiche Ergebnisse, die unsere Annahmen unterstützten.

Acknowledgements

First of all, I would like to thank Prof. Jan Borchers who inspired me to develop my own piece of hardware with his lecture *Designing Interactive Systems I*.

Secondly, I thank Flo (Florian Heller) who always listened to my suggestions and problems when I came around (spur-of-the-moment).

Finally, I want to thank all my little helpers.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

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

Definition:
Excursus

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

Source code and implementation symbols are written in typewriter-style text.

`myClass`

The whole thesis is written in American English.

Download links are set off in coloured boxes.

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[a] http://media.informatik.rwth-aachen.de/~kluth/thesis/file_number.file

Chapter 1

Introduction

For the past few years the climate change has been a huge public topic. Since the impacts of CO_2 emissions and the dangers arising from unsafe nuclear power plants became a significant threat, we are looking for clean, safe, and environmentally friendly energy resources. The futures belongs to the renewable energies like solar-, water-, and wind-energy. However, the hunger for energy increases and it will take years to compensate our energy consumption. Thus, the need to save energy becomes more and more important.

According to Verband der Elektrizitätswirtschaft e.V. (VDEW), in Germany, the industry is by far the largest energy consumer (47% of the total energy consumption). But it is followed by private households with 27% of the total consumption and this percentage is not about to drop [envia Mitteldeutsche Energie AG, 2011]. Most electronic devices have an increasing need for power. The IEA (International Energy Agency) calls the increasing power consumption of electrical appliances in private households ”dramatic” [Dambeck, 2011]. The question is how to save energy? A solution needs to be found.

We assume that people are not aware of their energy consumption because electricity is invisible and not tangible. They need support to gain a feeling for power consumption and thus to initiate a change. A device which helps them to become attentive to their behavior concerning energy use could help. The Personal Energy Meter or in short PEM is such a device (see Figure 1.1). It shows the power consumption of a plugged-in device on an LCD display.

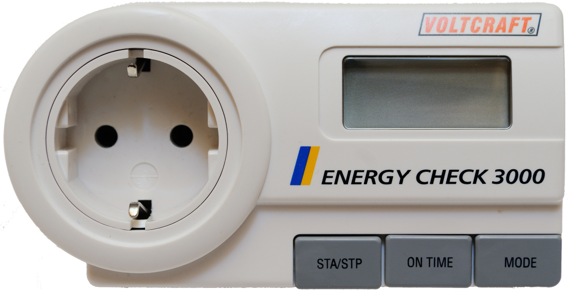

Figure 1.1: Personal Energy Meter (PEM)

Unfortunately, nobody really uses these smart meters. We tried to find the reasons for that and looked for alternatives to PEM. Based on our findings we delevoped our own ambient information system which is supposed to be more appealing and useful to the energy consumer.

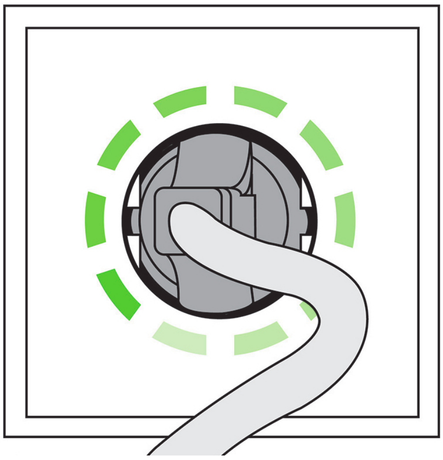

Figure 1.2: Illustration of PowerSocket

1.1 Power Socket

PowerSocket is an ambient information system integrated into the electric socket. It visual real-time feedback for power consumption of plugged in devices with ambient light.

AMBIENT INFORMATION SYSTEM:
Mankoff et al. [2003]: ″Ambient displays are abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user′s attention... They generally support monitoring of non-critical information.″ ″Ambient displays have the ambitious goal of presenting information without distracting or burdening the user.″

Definition:
Ambient Information System

We worked out five different visualization types and then decided to build a hardware prototype with a rotation visualization. The rotation visualization consists of a luminescent spot spinning around the socket. The rotation speed and the color are determined by the power consumption.

Chapter 2

Related work

2.1 Consumption Feedback Systems

In this section we will present a set of different ambient information systems. Most of them are covering a specific area in Eco-visualization and we will refer to these systems in later chapters.

Overview of existing ambient information systems.

2.1.1 Power-Aware Cord

The Power-Aware Cord is a direct feedback system for power consumption of electric appliances, developed by Gustafsson and Gyllenswärd [2005]. The main purpose of this project is to present the actual power consumption of one or more devices with an ambient light which is embedded into an electrical cord.

The initial hypothesis of the project is that it is easier to read energy from an ambient light than from a numeric display. The prototype of Power-Aware Cord is a modified power strip. The ambient light is realized with three electroluminescent wires which are wrapped around the power cord. When the light is on, each of the wires glows in an intensive blue-green light. When it is off, the wires shine white. The control part is embedded into the case of the power strip.

Real-time feedback for power consumption

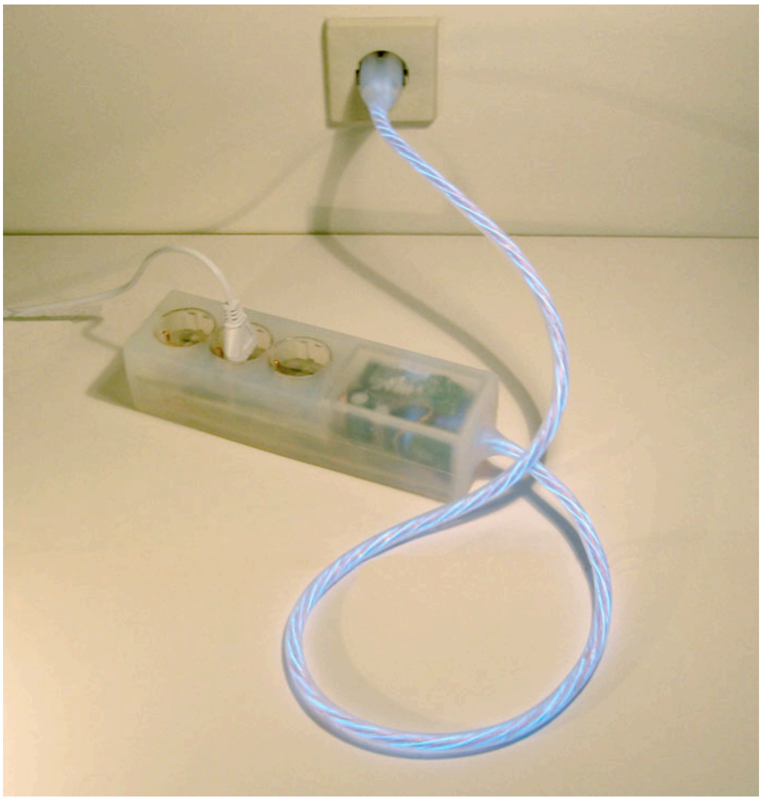

Figure 2.1: Power-Aware Cord with illuminated Cord

Three different visualizations were implemented: *static intensity*, *pulsating intensity* and *flowing intensity*. These visualizations were tested for intuitiveness and perception in a user study with fifteen participants.

Comparing PowerSocket with the Power-Aware Cord, the underlying idea to present direct feedback about the user's power consumption via an ambient light is the same. Nevertheless, there are some points which distinguish the two prototypes. Our visualization is embedded into a socket which shows the power consumption of electric devices right at the place of usage. It is more difficult to replace it or to turn it off. Furthermore, we have detailed visualizations and can animate different motions in a fluent way. We think this is very important for visual feedback of ambient information systems.

Figure 2.2: The Ténéré - Socket Edition (low load) and Tree Animation

2.1.2 The Ténéré

Kim et al. [2009] developed Ténéré, an electrical power extension cord which provides metaphoric feedback about power consumption. They intend to connect the effects of electrical usage with environmental impacts through a metaphor about *The Tree of Ténéré*.

A emotional presentation of the impacts of energy waste.

The Tree of Ténéré was the most isolated tree in the world and was replaced by a sculpture after its death. The main component of the prototype is a display embedded into the power extension cord. There is an animation showing how the tree changes into the sculpture and vice versa depended on the power consumption. A healthy tree represents low energy consumption, while the sculpture represents energy wasting.

PowerSocket and Ténéré follow two different approaches. Our approach provides easy readable real-time feedback to the user with the intention to make him more aware about his current power consumption. Compared to our approach, Ténéré has a more meaningful and emotional strategy. It sensitizes the user to his influence on envi-

Figure 2.3: Wattbot - Technical Structure and iOS App

ronmental impacts. However, the user needs more cognitive load to interpret the visualization each time which can be exhausting. Further, our survey (3.3—"Survey: Power Consumption in German Households") shows that most people already have an understanding about the link between energy wasting and environmental impacts.

2.1.3 WattBot

WattBot is a residential electricity monitoring and feedback system developed by Petersen et al. [2009]. The main idea behind the project is the representation of electricity usage of private households on a mobile device, in this case especially on an Apple iOS device. The iOS application allows the user to view, compare and analyze his data at home and on the way.

An iPhone power consumption monitor application.

The technique behind this prototype is on the one hand an iOS application and on the other hand a data collection box which is connected to the home's circuit breaker box. This box divides the power supply line into several circuits for different rooms and appliances (e.g., air-conditioner and heater). In addition, the data collection box sends the wattage data from each of these circuits wirelessly by an iOS device. In the user interface of the application a circuit is represented by a color-coded bar and current power usage is visualized by an animated colored gradient.

WattBot is a system for experienced users who wish an explicit overview of the home energy consumption. In contrast to PowerSocket it shows some drawbacks, e.g., the user has to initiate the data request by starting the application, the user has to make an effort to understand the content and to evaluate the findings. The existence of an additional external device is a further drawback.

2.1.4 Wattson

Figure 2.4: DIY KYOTO Wattson

Wattson[1] is one of few commercial ambient feedback systems for households. It visualizes the power consumption of a whole household in a glowing, colored light and displays consumption costs or current wattage in kWh on a numeric display. Blue light shows that little energy is consumed whereas red light means a very high level of electricity use. Thus, fading from blue to red light indicates increasing power consumption.

Measure power consumption with aesthetic.

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[1] http://www.diykyoto.com/uk/

Figure 2.5: Energy AWARE Clock

PowerSocket and Wattson are similar in one point. Both use colored light to visualize power consumption. While Wattson uses colors between blue and red, PowerSocket takes a more common approach with traffic-light color-coding. Nevertheless, the main differences are the missing rotation animation, as well as the fact that Wattson uses aggregated data and PowerSocket data from only a single socket.

2.1.5 Energy AWARE Clock

A clock that shows not the time.

A similar approach to visualize power consumption is done by Broms et al. [2010] in their work for the Energy AWARE Clock. In addition to direct feedback of the current electrical usage, it also offers historical information about the consumption of the last three days.

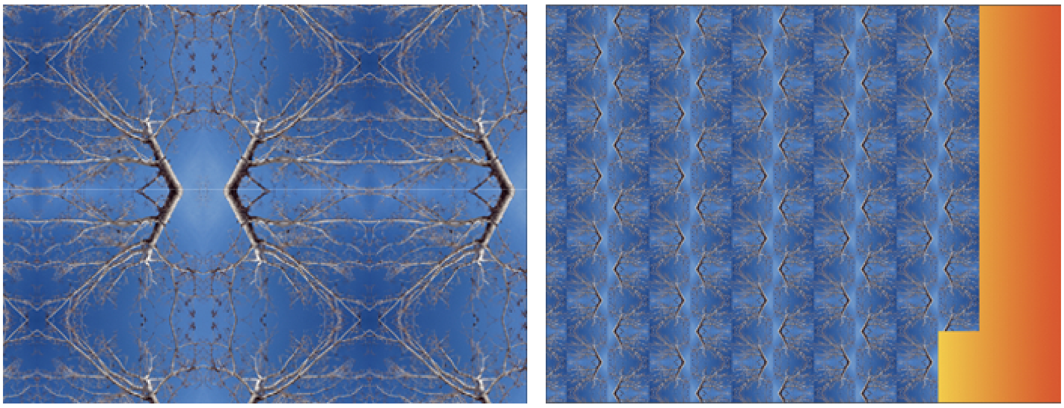

Figure 2.6: Tree Visualization from 7000 Oaks and Counting - low load (left), high load (right)

2.1.6 7000 Oaks and Counting

Holmes [2007] developed the Eco-visualization prototype 7000 Oaks and Counting. It is a public artwork in form of a lobby-sited kiosk, placed in the National Center for Supercomputing Applications (NCSA) in Urbana, Illinois. The designer intends to visualize the carbon footprint of a whole building by showing the carbon footprint of each resident using the representation of trees.

Sustainable artwork.

The prototype has three primary functions: (a) *environmental agitprop*, (b) *information visualization* and (c) *aesthetic experience*. (a) consists of getting power consumption data from the building monitoring system, converting it into the carbon footprint (measured in pounds of carbon dioxide) and from there into the number of trees (seven trees are equal to one pound carbon dioxide) which are necessary to reduce the emitted CO_2. (b) animates a higher footprint by displaying an increasing number of trees, while a lower carbon footprint is visualized by less but larger trees with more details. (c) treads artistic details.

2.1.7 UpStream

The three most investigated direct feedback systems with ambient visualization (Arroyo et al. [2005], Kappel and

Figure 2.7: Upstream - Ambient Shower Display

Figure 2.8: Upstream - Numeric Shower Display

Ambient information systems for water consumption.

Grechenig [2009] and Kuznetsov and Paulos [2010]) which have much in common with PowerSocket, have been developed for water consumption. Each of these systems estimates and displays water consumption only for a single faucet or shower.

In this section we will concentrate on the results of UpStream by Kuznetsov and Paulos [2010]. They compared four water consumption feedback prototypes in public and private space. To get water consumption data, they developed a low-cost sensor which measures the water flow by sound. Three of the displays are ambient and one is numeric. For our following work, the comparison of two shower displays, an ambient and a numeric, is of interest.

The ambient display has a glowing ball which indicates with the traffic-light metaphor how much water is used. The numeric display shows the current and average water usage in gallons.

In contrast to our previous discussions, here we are considering feedback systems for water consumption, whereas water and electricity consumption are two completely different things. You can feel, hear and see the water flowing. That makes it easy to find an initial point to set in relation with a numeric or ambient display. Power consumption does not offer such advantages. Nevertheless, studies have shown that the ambient display was more successful than the numeric display. For one participant the ambient display was ″more gradual″ and ″less stressful″ and another ″liked the flashing red light because it was more effective at getting her attention and conveying negative information, [...]″.

Chapter 3

Creating a PowerSocket

In this chapter, we will discuss the advantages of an ambient feedback display compared to an ordinary smart meter with LCD display. To figure out if the user is ready for PowerSocket, we created a survey about power consumption and electrical usage in German households. Additionally, a literature research will show assumptions about the effectiveness and importance of direct feedback systems.

In the following chapters we will present a software as well as a hardware prototype. The software prototype consists of a graphical application for the Apple[1] iPad which displays five different visualizations on a virtual socket. The hardware prototype is a modified electric socket which can display two of the five visualizations at the basis of real consumption data.

3.1 Beginning: An On-Outlet Display

It's always worth it.

On the one hand direct feedback systems are successful in reducing power consumption by 5-15% [Darby, 2006][Copeland, 2006] and real-time feedback raises awareness [Allen and Janda, 2006]. On the other hand continuous feedback can be exhausting. As a possible result the user re-

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

duces his attention regarding changes in his consumption behavior.

We created PowerSocket to provide a device which makes it easier and more pleasant for the users to be informed and aware about their energy consumption at home. An ambient display should decrease their active awareness, whereas continuous feedback changes their consumption behavior. Our approach is PowerSocket, a real-time ambient information system placed into an electrical outlet.

3.2 Does the World Really Need the PowerSocket

First, we will discuss some literature about the effectiveness of feedback from a psychological and a social point of view, instead of a technical perspective as previously done in chapter 2—“Related work”. ”Feedback came to be seen in terms of a learning tool, allowing energy users to teach themselves through experimentation.” [Darby, 2006] is a statement of Darby, one of the top researchers in sustainability. In her opinion, feedback helps the user to understand his current consumption by iterated interaction with the electric appliances and its resulting feedback. This leads to an understanding of energy use as a whole and helps reducing power consumption.

The model in Figure 3.1 describes the impact of feedback in combination of *tacit* and *durable knowledge*. When a person earns new *tacit knowledge* about energy use he successfully passed through the following three steps. (1) he needs information about energy use to realize a behavior change, then (2) he acts this way and as a last resort, (3) he understands the external changes by interpreting feedback. In sum, there are several ways to initiate a behavior change, but it needs continuous feedback to keep changing.

Another perspective about feedback and its effects came from Copeland who gives us an overview (see Figure 3.2) of the various types of feedback and the effects which lead to a behavior change. The starting point for our approach

Feedback and its impacts.

is *direct feedback*. Additionally, Copeland figured out that some specific attributes are important for a direct feedback system like PowerSocket - "[...] display, frequency, and presentation improve its quality." [Copeland, 2006]. This helps us to develop a system of our own. "The main goal is a presentation to capture their attention" [Copeland, 2006] is another important clue, because a better presentation of energy use feedback can increase energy saving about 10%-20% [Stern, 1992].

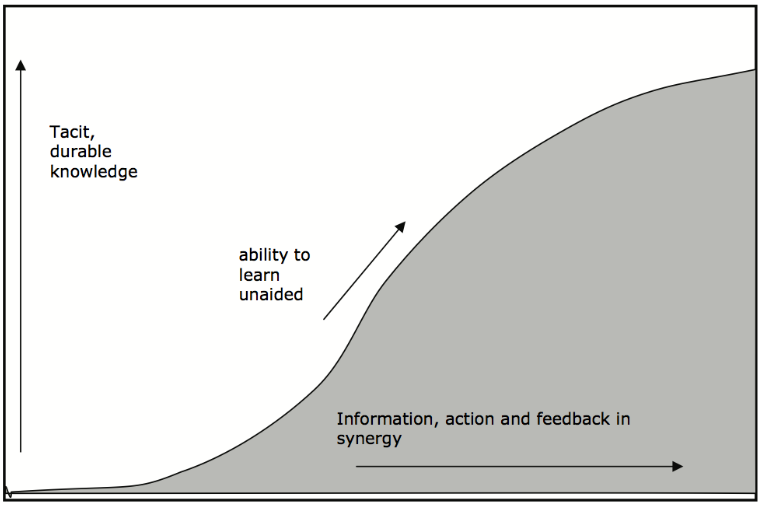

Figure 3.1: The Impact of Feedback in Combination with Tacit and Durable Knowledge by Darby [2006]

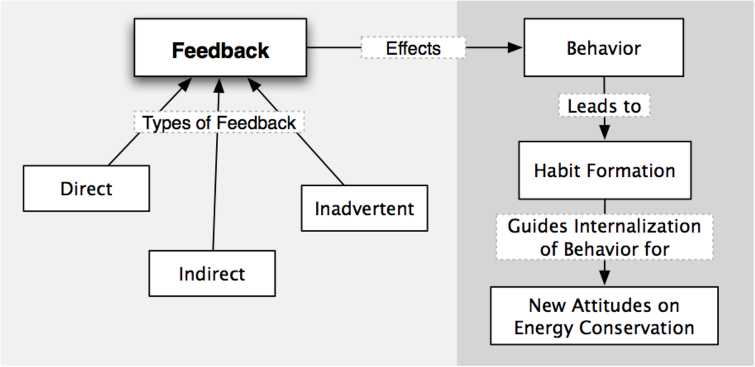

Figure 3.2: How Feedback and Behavior Work Together [Copeland, 2006]

3.3 Survey: Power Consumption in German Households

- Who is the user?
- What is his knowledge about energy consumption?
- What are his attitudes, beliefs and values considering electrical use?

Before we begin with developing our approach, we need to find answers for these questions.

We claim that there are significant differences between nations, territories, and education which influence the success of a direct feedback system. He et al. [2010] developed a motivational framework applying the *Transtheoretical Model* (also known as *Stages of Behavior Change*). In their opinion, a behavior change is not a single process, but rather a series of five stages (from *Precontemplation*, over *Contemplation*, *Preparation*, and *Action* to *Maintenance*). Motivation, effort, and energy are the components to reach the next stage. Our hypothesis argues that the average German household can be located in the middle of the hierarchy, between *preparation* and *action*. According to He et al. [2010], information systems like PowerSocket can be powerful in *preparation* and *action*, because the user has formed a goal in his mind and can take action to reach this goal, triggered by feedback.

TRANSTHEORETICAL MODEL [HE ET AL., 2010]:
Precontemplation: The individual is on a stage where it is totally isolated from his behavior problem.
Contemplation: He realize that the behavior is a problem and plans changes during the next six month.
Preparation: The individual develops a plan how he can take action in near future.
Action: The individual acts for a behavior change.
Maintenance: Each effort which the individual makes, serves the stability of his behavior change.

To provide support for our theory we conducted a survey with 248 people, living in Germany, published on the Internet. The participants consist of 57 women (23%) and 192 men (77%), and over 90% are between 19 and 49 years old. In general, they are highly educated, and their type of housing is distributed evenly between one-room, multi-room apartments and single-family homes, with the exception of apartments with 2-3 rooms which makes up the majority with 53%.

Survey results.

Only 20% of the participants stated that they do not turn off devices in standby mode. But, nearly 50% let their computer or television running while having a break.

Moreover, further statements confirm two major reasons for energy saving complains, laziness (63%) and habit (57%).

In contrast, missing knowledge about electrical power usage and its aftermath is not the major reason for inappropriate behavior. In questions about power consumption of home appliances (*estimate how high is the consumption level of the following device*; answer options in four steps from very little to very much) the participants estimated in most cases correct. For example, for 82% of the participants it is clear that a clothes dryer needs very much power. Same for the rating of a hair dryer, where 80% of subjects said it needs much or very much power.

83% of the people are familiar with personal energy meters like Kill-a-Watt[2] and 63% of them have used it, but only 4% are using it on a regular basis. However, the distribution is not unusual because smart meters are cheap (10-30 €) in Germany and, e.g., they one regularly offered in discount supermarket. Nevertheless, an issue remains. Why are only 4% of the participants using it regularly?

Smart metering is not unknown.

Most of the participants (86%) can imagine that more information about the current wattage could reduce electricity consumption. All in all, about 71% of the people answered that they try conserving energy at the moment.

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[2] http://www.p3international.com/products/special/P4400/P4400-CE.html

In short, a basis for a behavior change is given. A problem arose when we asked about smart metering. Although the majority knows about smart meter devices, nobody uses it. Is it a general problem, or does the problem consist of how the data is communicated? With PowerSocket we can try to give an answer to this question.

Chapter 4

A Taxonomy and Five Power Consumption Visualizations

In this chapter we discuss a taxonomy for power consumption visualization, the classification of existing visualizations, and a software prototype based on an Apple iPad that helps us compare different fundamental visualizations.

Some of this work has been published by Heller and Borchers [2011] at CHI 2011. We will pick up some of their ideas and research results in the course of this chapter.

4.1 Taxonomy: Classification of Existing Visualizations

First of all, a taxonomy for ambient information systems will help us to classify existing visualizations. This gives us an overview about existing approaches in ambient information systems and a detailed view of attributes which are important to build a set of fundamental and basic on-outlet visualizations for PowerSocket.

Adapting a taxonomy.

Heller and Borchers [2011] adopted a taxonomy from Tomitsch et al. [2007]. On the one hand, they removed four of nine dimensions (Notification Level, Source, Location, and Dynamic of Input), as they were not necessary for their research. Additionally, simplicity is significant for a good taxonomy (Fishkin [2004]). On the other hand, Heller and Borchers [2011] replaced the dimension "Abstraction Level" with the more accurate dimension "Representation Fidelity" (Pousman and Stasko [2006]) which provides a finer degree of categorization.

The following dimensions are removed from the original taxonomy: "Notification Level" (*ignore*, *change*, *blind*, *make aware*, *interrupt*, and *demand attention*) determines the point when it is necessary to interrupt or to alert the user that a state change has happened. For PowerSocket and any other ambient information system which is considered here, the "Notification Level" *make aware* is the same. "Source" (*local*, *distant*, and *virtual*) describes the distance between data source and display. We work only with power consumption data from a specific electrical outlet, room or house. This means their source is always *local*. "Dynamic of Input" (*slow*, *medium*, and *fast*) details the velocity of data changes. As each of the systems measures electrical usage, it is *medium* for everything. The last omitted dimension is "Location" (*private*, *semi-public*, and *public*) because it makes no difference for PowerSocket, as it can be used in private as well as in public space.

The dimensions of the taxonomy.

"Abstraction Level" (*low*, *medium*, and *high*) has the drawback that it is too imprecise to describe the complex and full dimension of abstraction. Pousman and Stasko [2006] decided to split up the different types of the dimension into *indexical*, *iconic*, and *symbolic* under the label "Representational Fidelity". The following points give an overview of the remaining dimensions with dedicated metrics and a short description.

- **Transition.** (*slow*, *medium*, *fast*) When data changes, the display will react such that the user becomes aware of it. A *slow* transition is unobtrusive and only heavy data changes lead to noticeable transitions while *fast* "Transition" reacts on every input change.

- **Representational Fidelity.** (*indexical*, *iconic*, and *symbolic*) "Representational Fidelity" describes the encoding of data into an easy and fast representation. *Indexical* signs have a direct relationship to the data while *iconic* signs build a bridge from the data to a similar representation. *Symbolic* signs are totally arbitrary. For a better understanding, we illustrate a list of five groups by Pousman and Stasko [2006]. It is ordered from *indexical* (high) to *symbolic* (low).
  - INDEXICAL: measuring instruments, maps, photographs
  - ICONIC: drawings, doodles, caricatures
  - ICONIC: Metaphors
  - SYMBOLIC: language symbols (letters and numbers)
  - SYMBOLIC: abstract symbols
- **Temporal Gradient.** (*history*, *current*) Like the names of the metrics *history* and *current* show, the ambient information system can hold the information over a period of time or only for a moment.
- **Modality.** (*visual*, *movement*) Ambient information systems have different types of data visualization. While visual information design is typical, audio and movements of objects are also possible. In our case we will limit the dimension to *visual* and *movement*.
- **Representation.** (*physical*, *integrated*, and *2D*) An output device is either a LCD (*2D*), a device solely developed for this purpose *(physical)* or an existing (everyday) device which has been extended *(integrated)*.

4.2 Five Visualization Types

As mentioned before the intention of PowerSocket is an on-outlet ambient information system. This implies that the whole measurement technique and the visualization component is fully integrated into the electric socket. For the user there is no direct input or user interface, just a display

		Electricity Meter	Kill-a-Watt	Ténéré	700 Oaks and Counting	Wattson	Energy Aware Clock	Power-Aware Cord
Transition	Slow				■			
	Medium			■			■	
	Fast	■	■			■		■
Representational Fidelity	Indexical		■					
	Iconic			■	■			
		■					■	
	Symbolic					■		■
Temporal Gradient	History			■	■		■	
	Current	■	■			■		■
Modality	Visual		■	■	■	■	■	
	Movement	■						■
Representation	Physical	■				■	■	
	Integrated		■	■				■
	2D				■			

Table 4.1: Classification of existing power consumption displays along the different dimensions of our taxonomy by Heller and Borchers [2011].

Classify seven ambient information systems.

which shows him the current power consumption for a specific socket. To figure out what types of visualizations are relevant for our work we derived five visualizations from our taxonomy. Considering the huge number of possible visualizations and the fact that we are developing a specific ambient information system that measures power consumption, we concluded that three dimensions of our taxonomy are fixed. In detail, "Transition" is *fast*, "Temporal gradient" is *current* and the "Representation" is *integrated*.

A set of five extracted visualizations.

"Representational Fidelity" *(indexical, iconic, and symbolic)* and "Modality" *(visual, movement)* are the two dimensions which remain. With the background of our study (cf. section 3.3—"Survey: Power Consumption in German Households") and the constraints of size and feasibility, we left out *iconic* representations like the metaphorical visualization of the Ténéré prototype (cf. section 2.1.2—"The Ténéré"). In combination with well known visualizations (see Figure 4.1) we got five individual visualizations (**Rotation**, **Pulse**, **Spin**, **Bar graph**, and **LCD**) customized

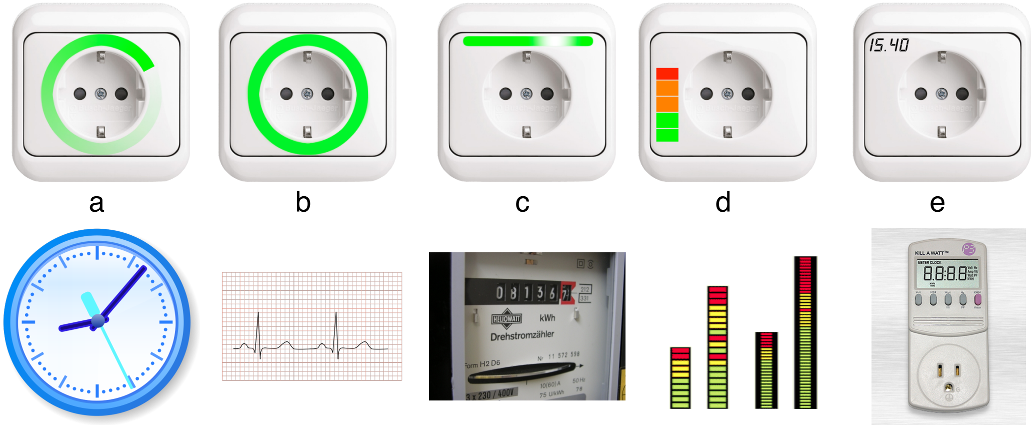


Figure 4.1: The different visualizations and their real-world counterparts by Heller and Borchers [2011].

for an outlet. The connection to a familiar display is necessary to give the user a point of reference and to keep the abstraction level low.

a) Rotation. As can be seen in figure 4.1, ”Rotation” is formed as a colored stripe that moves around the plug. Rotation speed and coloring are feedback indicators. Slow rotation stands for a low load while fast rotation implies a high load. The number of rotations increases non-linear and reaches a high point early to become stagnant afterwards. In addition, color follows the traffic light color coding. That means, from low to high load it fades from green over yellow to red, but in contrast to movement it changes linearly.

b) Pulse. The ”Pulse” visualization consists of a colored ring around the plug which pulsates from no to full brightness with a fixed pulse-frequency (60 Hz). That means we only use colors to give a feedback. Color coding is the same as in ”Rotation”. Since the focus of feedback is on color coding, we decided that the ”Modality” of this visualization is *visual* and not *movement*. Further, the dimension ”Representational Fidelity” is clearly *symbolic*.

c) Spin. The ”Spin” visualization is similar to the intention of the spinning disc of an electrical meter. A white spot is located in a green bar above the plug and when the spot dis-appears at the end of the box it starts from the left side immediately. During power consumption the bar moves from left to right in an endless loop. For low load the spinning speed is slow, while under high load the speed is fast. The spinning speed increases identically to the speed of "Rotation" (non-linear). Like "Rotation", we sorted "Spin" into the taxonomy as *symbolic* and *movement*.

d) Bar graph. The "Bar graph" visualization consists of a 3-colored LED bar graph placed on the left side of the plug. It has the form of a small vertical rectangle and it is divided into six horizontal segments with the same height. Parallel to the power consumption a horizontal bar moves from the bottom to the top and colorizes everything underneath. The lowest two segments become green when low energy is consumed. In addition, when more energy is used the two middle segments turn yellow. In the direction of the maximum of electrical usage the highest remaining segments turn red. Since there is no motion in the *bar graph* we classify it as *visual* and *indexical*.

e) LCD. The "LCD" visualization shows the current wattage on a 4-digit LCD display (up to two decimal places), placed on the top left corner of the socket. As you can see in figure 4.1, it is an on-outlet socket version of 'Kill-a-Watt' with restricted functionality. Like 'Kill-a-Watt' it is classified as *indexical* and *visual*.

After having found a set of five visualizations for an on-outlet display it is time to figure out which of these are the most successful solutions. But before, we have to assume some theoretical conditions for our data, the power consumption for a single socket measured in Watt. In our case an electric socket is connected to a circuit and the circuit itself is protected by a 16 A fuse. As we work with a voltage of 230 V, that implies a theoretical maximum power of 3680 W. It is a theoretical value because in an average household there are several sockets connected to a circuit and share the maximum power. For all visualization types the maximum is necessary because it influence the resolution of the representation of power consumption.

When we talk about power consumption we are not talking about Wh which means measuring electrical usage above a period of time. In our context power consumption is the wattage in W at the moment because we are considering real time data for electrical devices.

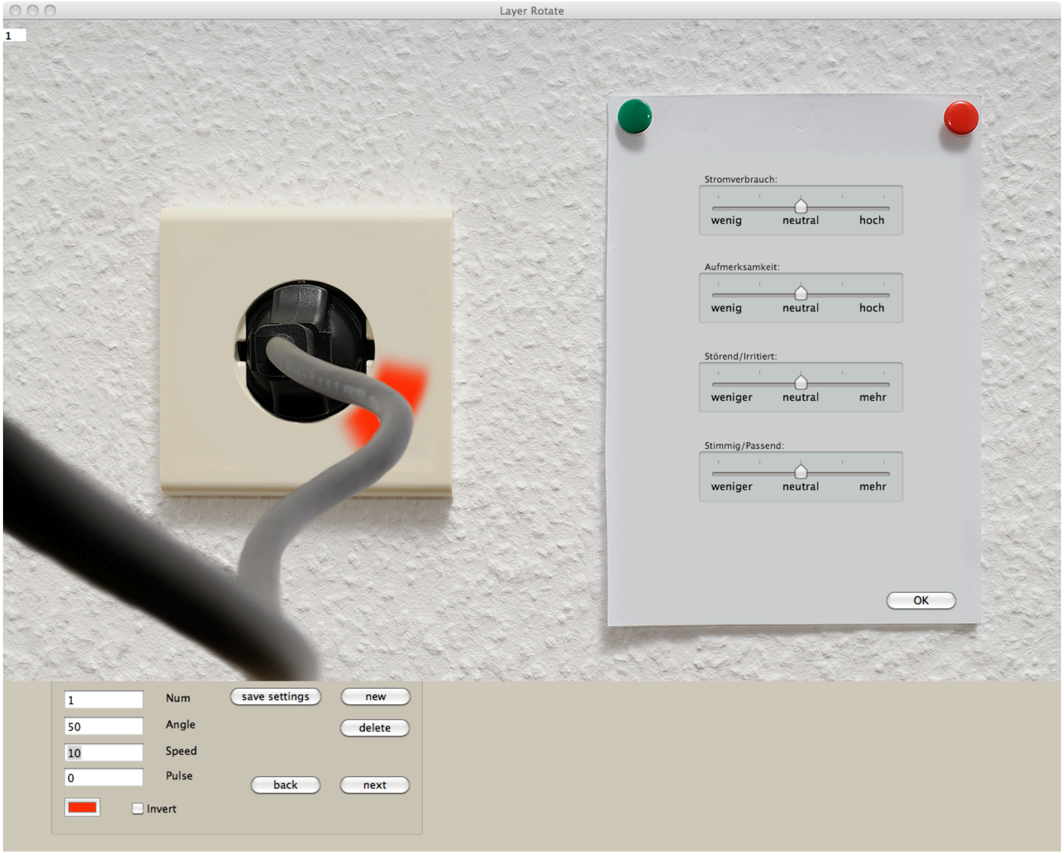
Chapter 5

Software Prototype

In this chapter we will test and compare the different visualizations among each other in a user study. For this purpose we built a software prototype for the Apple iPad augmented with a real power cord.

5.1 First Prototype: Desktop Version

In our case a software prototype was the best solution to present several animated visualizations with varying motion speed and color. First, we began with a software prototype for an ordinary computer system (see Figure 5.1) and started with the creation of the *Rotation* visualization. The user interface of the software consists of three pieces, the visualization, a questionnaire, and an interface to control the animation in speed, color, and number of rotators. We stopped this prototype in progress because we found significant issues while testing. The biggest problem consists of the fact that the user should sit directly in front of the computer system. We intended that the user rates and manipulates the visualization on his own. The full awareness of the user and the completely wrong position of the prototype lead to the decision to stop this approach and find another one with a more appropriate setting. Our goal was



1 Num
50 Angle
10 Speed
0 Pulse
☐ Invert

Figure 5.1: First Software Prototype on a Computer System

a realistic prototype that should work without direct input of the user. In general, it should be very similar to the end version of PowerSocket. We decided to develop a *virtual* PowerSocket for an iPad placed on a wall like a real electric socket (see Figure 5.2).

5.2 Second Prototype: iPad Version

The iPad Prototype.

The iPad offers a few important advantages over the ordinary desktop system prototype. It makes it possible to create a software prototype as a real piece of hardware which can simulate the PowerSocket as we intend. It is small enough to hang up on a wall, the IPS-panel of the display has an extreme good viewing angle and the hardware is

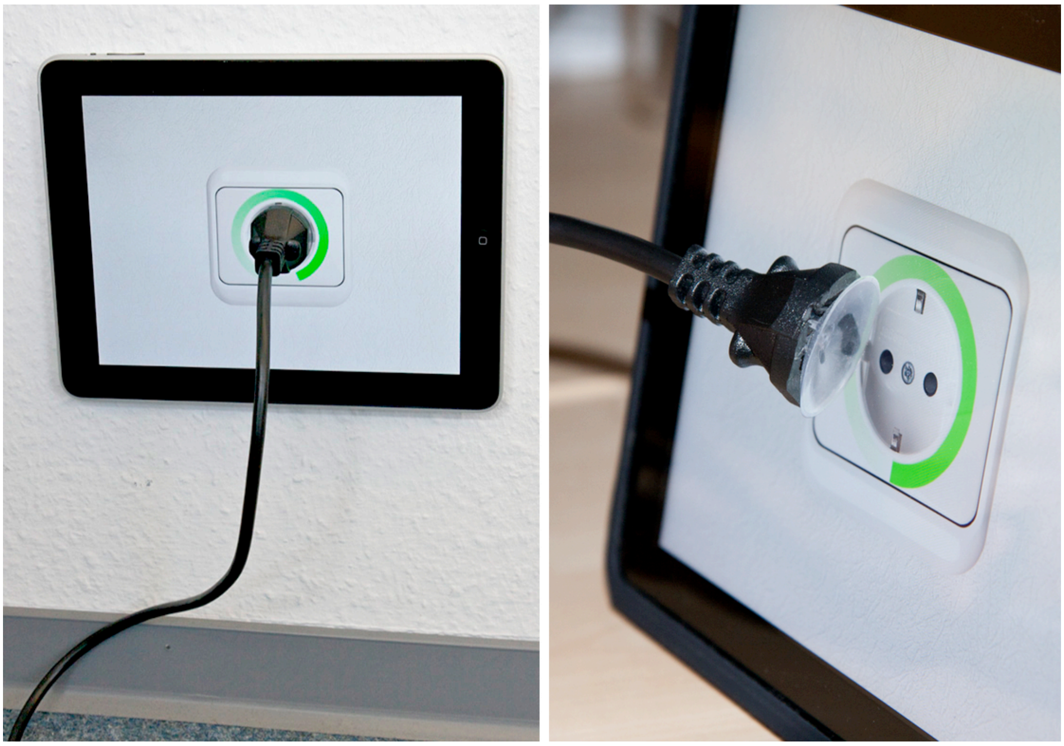


Figure 5.2: Virtual PowerSocket - Passive Visualizer

fast enough for fluid animations. Additionally, via Wi-Fi we can control the prototype from a computer system.

The whole prototype consists of two components connected wirelessly. First, the iPad which presents the different visualizations on a virtual PowerSocket, and second, an Apple Mac which we used to change the visualization type and the power consumption of the iPad application.

We developed an application for the iPad which displays a texture of a plain wall and picture of an electric socket. With the help of the CoreAnimation framework we could easily implement the animations of our visualization types. To make it more realistic, we modified an electrical cord and removed the pins of the plug and replaced them by a suction cup (see second picture of Figure 5.2). This makes it possible to connect the cord to the virtual electric socket without modifying the iPad. As shown in Figure 5.2, the prototype awakes the illusion of a real electric socket with a cord plugged in. The software of the iPad calculates motion speed and color for each visualization while the controller software changes only the visualization type and the power consumption value.

The controller software.

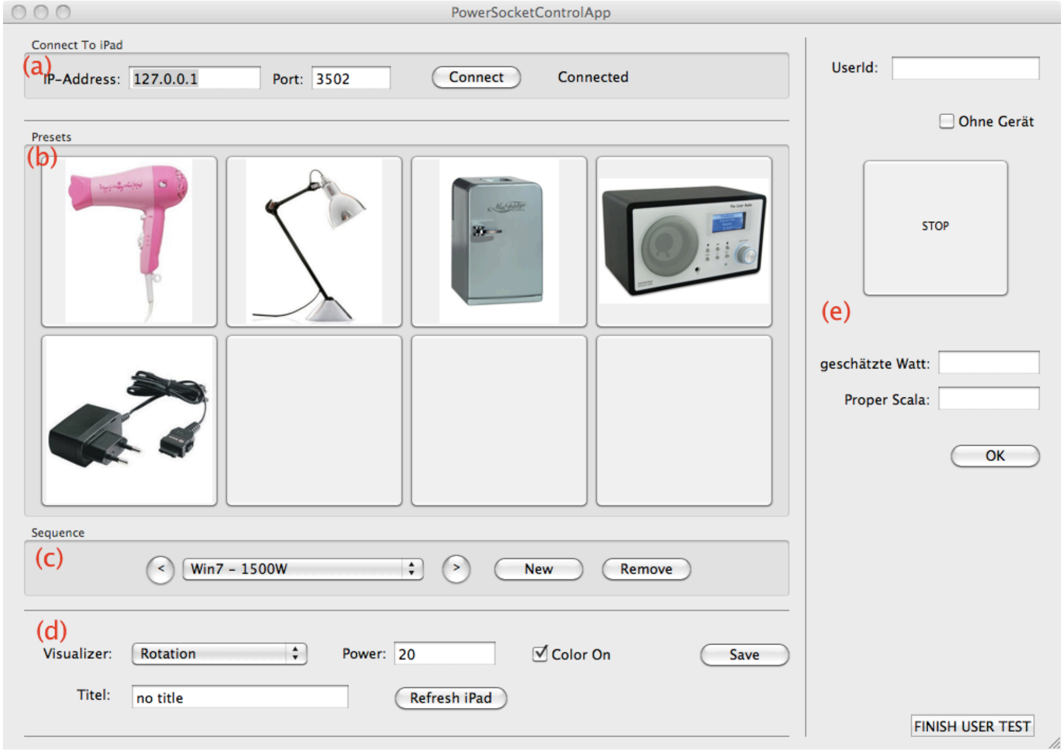
The controller software for an Apple Mac system is especially developed for the following user study and controls the visualization and the power consumption level of the iPad software. There is also a little form for a test and it is possible to save the session in a XML-file. Figure 5.3 shows that our software consists of four components ((a) connection settings, (b) visualization preset buttons, (c) visualization sequence, (d) manual visualization control, and (e) a form). For an easy and fast use, the preset buttons (b) are defined with fixed values and display pictures of devices which are equivalent to their consumption load. The sequence (c) of presets supports going through a predefined set of visualizations. In combination with the form it allows to quickly collect data. For each sequence item the software saves the results from the form into a XML file declared with date and user ID.

5.3 Evaluation

In the following we present our user study and the results based on a software prototype (cf. chapter 5.2—"Second Prototype: iPad Version"). We intended to figure out if the participants realize a connection between the visualizations and power consumption and designed a Wizard of Oz experiment [Dix et al., 2003]. We were also interested in the user's opinion about visualization types and asked him about some quality aspects.

5.3.1 Subjects

We had 14 participants (12 male, 2 female) with the age between 22 and 54 years (average age 29) who attended our user study. Nine of them are studying a technical subject, four employees, and one is a housewife. We asked a set of questions about power consumption from our previ-



PowerSocketControlApp

Connect To iPad

IP-Address: 127.0.0.1 Port: 3502 Connected

UserId:

☐ Ohne Gerät

Presets

Sequence

Win7 - 1500W

Visualizer: Rotation Power: 20 ☑ Color On

Titel: no title

geschätzte Watt:

Proper Scala:

Figure 5.3: Control Software for Software Prototype - (a) Connection Settings, (b) Visualization Preset Buttons, (c) Visualization Sequence, (d) Manual Visualization Control, and (e) Form

ous survey (3.3—"Survey: Power Consumption in German Households") and received nearly the same results. Eleven subjects (79%) claim that they know smart meters like 'Kill-a-Watt' and five (36%) have used them once.

5.3.2 User Study Design

A quantitative and qualitative user study.

Our user study was separated into a quantitative and qualitative part. For both, we had the same arrangement in all tests. The iPad was placed on a wall in the same height as a normal electric socket (Figure 5.2) and the subject sat facing to the prototype with a distance of 1.5 - 2 meters. The interviewer was seated next to the subject such that the subject could not see what the interviewer did on the control system. The user test had an average time of 20 minutes and was proceeded in the following order:

Quantitative Study

The quantitative study was separated into two parts. First, we created a sequence for four settings (5.1—"Sequence Settings") and each visualization type in randomized order (a total of 20 sequence items). We started to show the participant one visualization and afterwards he had to estimate the power consumption in watt. We repeated this procedure for the remaining 19 consumption samples.

Power Consumption Category	Power Consumption in Watt
Low	1 - 5
MidLow	30 - 60
MidHigh	300 - 600
High	1500 - 1900

Table 5.1: Sequence Settings

Second, we simulated attaching a series of electrical appliances (vacuum cleaner, bulb light, energy saving bulb, modern television, and power supply unit) by showing a picture of it to the participant and by announcing it. In the same moment we activated a specific visualization with an energy level according to the selection. For each item we asked the subject to rate how well the visualization fits the attached device.

Qualitative Study

In the qualitative part the subject got a second chance to get an overview of a visualization and the different settings. Then he had to rate between *very easy* and *very hard* in five steps to the following characteristics adapted from Mankoff et al. [2003]:

- **Consistent and intuitive mapping**
  How difficult is it to understand the visualization?
- **Visibility of state**
  How difficult is it for you to read the consumed power with this visualization?

- **Aesthetic and pleasing design**
  How pleasing do you find the design of the visualization?

- **Peripherality of the display**
  How obtrusive do you find the visualization?

We repeated this procedure for all of the five visualization types and at the end of the test the subject got some time for comments.

5.3.3 Results

Results of Quantitative Study

We got no clear and convincing results. We think that the subjects realized the steps between *low*, *lowmid*, *highmid*, and *high* power consumption and ordered them correctly most of the time. It gives us a clue about our hypothesis that a connection between our visualizations and the power consumption exists. However, at the end the results were too imprecise and we had too much aberration for a useful outcome.

Results of Qualitative Study

In contrast to the other visualization types, the *LCD* type was rated as well and easily readable. As we expected, the subjects sense of it as calm and less obtrusive. We found no significant differences between the four ambient visualizations. The ratings for their characteristics all laid in the middle of the field, apart from the pleasing design which was better rated for ambient types.

Finally, we collected some very interesting feedback about the various visualization types. In the following we will give an insight into the most interesting and beneficial comments by the participants.

"I wouldn't notice it when passing by" was a statement about the *LCD* visualization which was often mentioned by participants in a similar form. Ambient information systems have the opportunity to present information without focusing. This is definitely a problem for any numeric display like our *LCD* version where a lot of cognitive load is necessary to read information from.

"I don't see any relation to the attached appliance. It is just a number" is again about the *LCD* type but this time the statement stays isolated. Considering the participants, the majority has a qualified technical background and we assume that they are familiar with abstract physical units. On the other hand, children and people with minor knowledge about electricity will certainly come to the same conclusion. Perhaps, this group of people are more qualified for a future user study.

"It [pulse] is very simple and clear if I differentiate only three categories" and "[...] I can divide that [rotation] into four to five categories like standby, below 20 W, normal consumption and electricity hogs." are statements which highlight the advantages of ambient visualizations. Presenting each consumption level rapidly is the major benefit in contrast to traditional displays. Nevertheless, a simplified perception leads to a classification in less categories.

"With the LCD, I have to decide if 100 W are good or bad [...] With the colors, this decision is made for me, but I get an idea what it's all about. I don't know if 100 W are green, yellow, or red.". This quote shows that color-coding is a great thing. In our culture the traffic-light metaphor is obvious and the color red has a clear message for warning and stop. The subject does not have to think a lot about it before he will act.

A problem was mentioned because most ambient visualizations (*Rotation*, *Pulse*, and *Spin*) provide no visible maximum. Nevertheless, nobody mentioned that problem for the *LCD*, despite the fact that it has no maximum either. The only visualization type with a visible maximum is the bar graph which has a full bar when it reaches the theoretical maximum power. It is a general issue whether it is necessary and useful to set the physical maximum to a visible maximum or to use a maximum at all. Comments about *Bar graph* suggest that in the user's perception it is alright to nearly reach the maximum but not recommendable to reach it totally. Briefly, the power consumption is okay as long as you do not reach the maximum. But this is absolutely incorrect and makes no sense for a sustainable approach. The ambient visualizations without visible maximum always have an infinite loop of motion. This process repeats itself until the power consumption stops. The benefit is a clear visualization of continuous power consumption.

Three subjects said that the pulsation (*Pulse*) is kind of annoying and it makes them feel urged to unplug the device immediately. The color made no difference, it is more about the persistent frequency. We assume that this visualization is useful for *low* power consumption and can extend other ambient visualizations to motivate people to unplug standby devices.

During the process of the user study attention was drawn to the placement of the prototype. The iPad was clearly visible and in front of the user. In conventional households the electric socket sometimes is behind furniture and not fully visible. In this case the *LCD* display is completely useless because it is invisible to the user. We suppose that the light and the motion of the ambient visualizations are still visible enough, so that the user notice it.

Chapter 6

Hardware Prototype

In chapter 5—“Software Prototype” we collected a few new aspects about the visualization types and how they may be improved. Nevertheless, we got no favorite one. Considering time and cost for building our first hardware prototype, we had to decide which type we were going to realize. We think that a RGB-luminescent ring around the plug as in *Rotation* and *Pulse* is a good solution. For our current hardware prototype and the following user study, we will only build a *Rotation* and *Pulse* version.

The first hardware version of our PowerSocket prototype consists of a combination of *Rotation* and *Pulse* visualization. For low power consumption, i.e., under 1 W, *Pulse* is activated, while *Rotation* is active in all other cases. Furthermore, it is also possible to deactivate the *Pulse* visualization completely with a switch on the backside of the prototype, such that *Rotation* covers the whole consumption range.

In the following sections we will discuss the way we built and programmed our hardware prototype, which is separated into *Data-* and *Visualization-Unit*, and we will look at the problems which were associated with it.

Any hardware part we used was produced in the FabLab[1] of the Media Computing Group Aachen.

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[1] http://fablab.rwth-aachen.de

Figure 6.1: PowerSocket Hardware Prototype

6.1 Data-Unit: Getting Power Consumption Data

Measuring power consumption.

According to Pierce et al. [2008], Eco-visualizations and also ambient information systems are divided into data and visualization. We treated the visualization part in the previous chapter 5.2—"Second Prototype: iPad Version". While it is clear for us what we want to measure, i.e., the wattage of the appliance which is plugged into the PowerSocket, it is not obvious how we will realize it from the technical point of view.

6.1.1 Hardware

How to build your own data-unit.

A safety issue arises when we measure the power consumption of electrical devices while they are connected to the electric circuit of a household which works with 230 V voltage. We worked with a prefabricated PEM to reduce the risk of an electric shock. However, we have two criteria for measuring, first, we need real-time data, i.e. the refresh rate is not longer than one second [Nielsen, 1994], and second, we need precise and accurate data.

We chose a 'KD 302'[2] smart meter with a Cirrus Logic[3] 'CS5460A' Power/Energy IC. It measures data from 0.2 W and updates energy changes every second. In addition, another advantage is the low price of approx. 10 € per device, so we can produce more than one prototype without any financial effort. Nevertheless, we had no direct access to the device's data because it has no interface for externals. This was the next problem we had to solve.

A solution was found by analyzing the communication between the measuring chip and the microcontroller of the device. The 'CS5460A' sends its data to the 'KD 302' over SPI (Serial Peripheral Interface Bus). It is more a hack than a real solution. We sniffed the communication of the SPI bus

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[2] http://www.reichelt.de

[3] http://www.cirrus.com

with our own microcontroller, an Arduino Duemilanove[4] , and logged the entire data flow from the 'CS5460A' to the smart meter microcontroller.

The SPI bus has four different logic signals (*SCLK*, *MOSI*, and *MISO*, $\overline{SS}$). When we listened to the data signals which go from the 'CS5460A' (*slave*) out, the signals of *SCLK* (Serial Clock) and *MISO* (Master Input, Slave Output) were of interest. Of the data signals which the microcontroller (*master*) sends, *MOSI* (Master Out, Slave In) is not important and $\overline{SS}$ (Slave Select) is always LOW and connected to ground for our project.

However, we could not connect the Arduino directly to the bus because we had a technical problem which could become very dangerous and could at least destroy our hardware when we connected the two devices. There would be a ground conflict between the ground reference of the smart meter and the ground reference of the Arduino, if they were connected to different power circuits with detached ground (see 'CS5460A' Datasheet[5] p.16). To solve this problem we added galvanic isolation for any wire between Arduino and 'CS5460A'. For this purpose we built a small opto-isolator PCB and put it in a box to avoid accidents by contact. An opto-isolator or optocoupler divides a circuit into two galvanic isolated pieces. It transforms the electrical signal, for instance with an LED, into a light signal. The light signal is interpreted by a photosensor on the other side of the circuit and transforms it again into an electrical signal.

After we connected the *SCLK* and the *MISO* channel from the 'CS5460A' over the opto-isolator PCB to the compatible pins of the Arduino, we got the data we wanted.

6.1.2 Software

As mentioned before we used an Arduino Duemilanove as microcontroller. With the Arduino programming language it was really easy to program and we could use the SPI

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[4] http://www.arduino.cc/

[5] http://www.cirrus.com/en/pubs/proDatasheet/CS5460A_F4.pdf

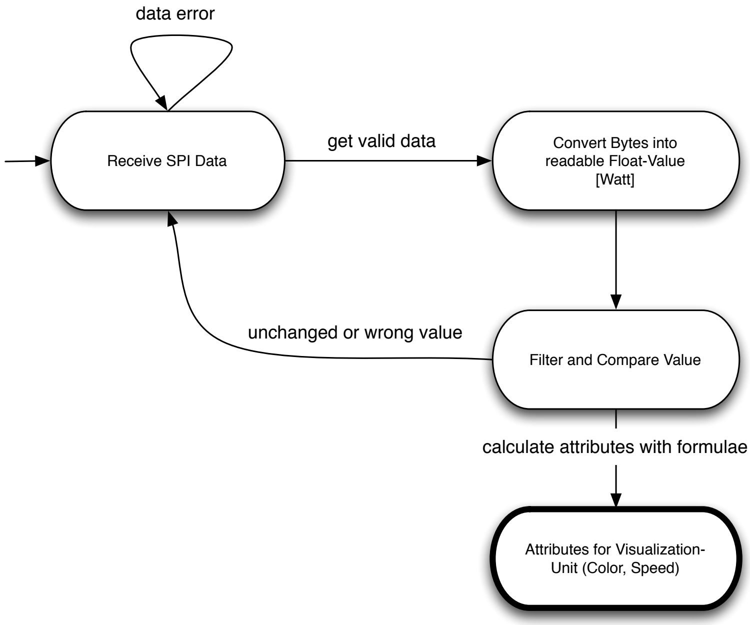

Figure 6.2: Measuring Process of the Hardware Prototype - Getting and Evaluating Sniffed Data

framework of the Arduino SDK to read out the incoming data.

The chart in Figure 6.2 shows the basic steps of our application. The program is in a loop most of the time until it gets a significant and unique string of data which contains the value of the current wattage. After the routine got the data, it has nearly one second to execute other program parts until the next data will be received. During this period it performs a set of basic methods, it converts the incoming bytes into a float number with the current power consumption in watt, it smooths the value with a low-pass filter (smoothing factor: $\alpha = 0.9$) and filters out insignificant and wrong values with a predefined threshold ($\beta = 5\%$). When it gets a correct value which differs from the predecessor, it calculates the appropriate values for the attribute of the visualization (color, motion speed, and if *Rotation* or *Pulse* is selected). The attribute values are sent as a package over the RX/TX Serial Communication to another Arduino of the same type.

Figure 6.3: Visualization Unit: *Rotation* Integrated into Self Made Wall Socket (*Low*,*Mid*, and *High* Energy Consumption)

6.2 Visualization-Unit: Rotation Display

The next step of building our prototype is straightforward: recreate the visualizations *Rotation* and *Pulse* with real hardware and place it into an ordinary electrical outlet.

6.2.1 Hardware

How to build your own visualization-unit.

The visualization-unit consists of three parts, a LED-PCB (printed circuit board) with 20 LEDs arranged in a circle around the plug (see Figure 6.4), again an Arduino which receives the evaluated data from the data-unit and controls the LEDs, and a self made electric socket with a diffuse acrylic ring around the plug which contains the LED-PCB.

We control the brightness of each LED of the LED-PCB over I^2C (bidirectional 2-wire bus) with an Arduino. The program which runs on the Arduino is explained in the next section (6.2.2—"Software").

The LED-PCB board was separated into four equal pieces with five SMD RGB LEDs (Osram[6] LATB T686), a 16 bit LED driver (NXP[7] PCA9635) and 15 resistors, one for each diode. On the backside there are four contact joints to get a range of four addresses, which means each quarter has its

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[6] http://www.osram-os.com

[7] http://www.nxp.com

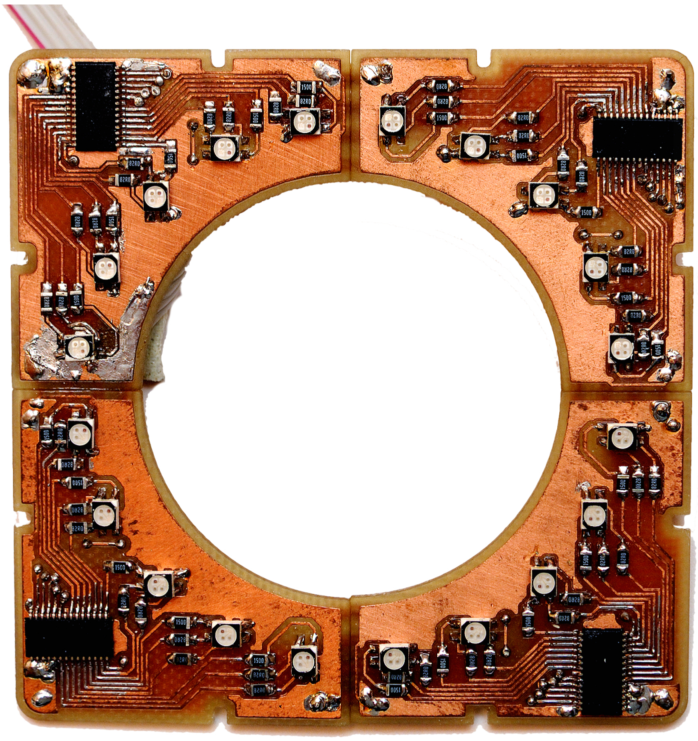

Figure 6.4: Visualization-Unit: LED-PCB (Printed Circuit Board) - *front*

own address. The Arduino is connected to the LED drivers and we can address each individual LED-Driver to control any of the five RGB LEDs. At the end, the quarters were put together to a single ring and this was placed into the case of the electrical outlet.

The wall socket consists of two components, a prefab backside and a custom-made front. The backside has the advantages that it is ready to use and compatible to DIN 49440/441 (SCHUKO). The front part is not from an existing product because there are two criteria which it has to fulfill. It needs a transparent and diffuse ring around the plug because the light of the LEDs has to be be seen from the outside and it needs enough space to carry the LED-PCB inside. The first step towards our own socket solution was to create a 3D CAD model (see Figure 6.5) which is composed of two parts, the frame and the diffuse acrylic

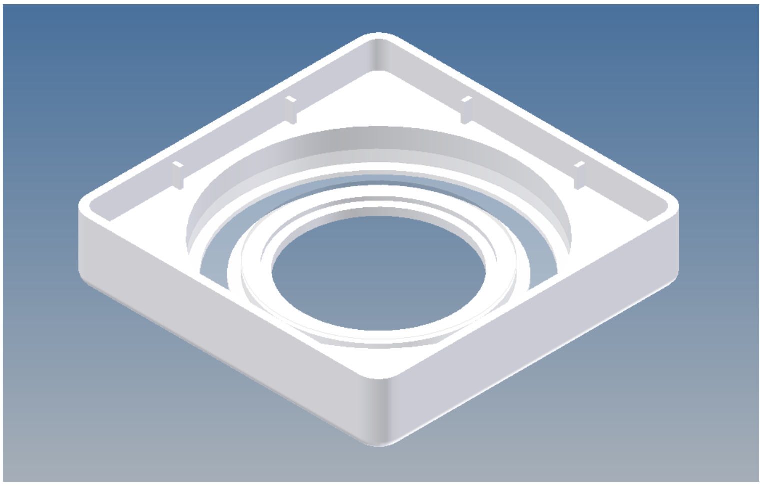

Figure 6.5: Visualization-Unit: 3D Model of PowerSocket Custom-Made Front

ring. The frame was printed in a 3D printer and it was painted white afterwards. For the diffuser ring we took a specially diffused acrylic (Evonik[8] PLEXIGLAS truLED) developed especially for LED light and it was cut with a lasercutter. The ring has an inner radius of 55 mm and an outer radius of 65 mm. At last, the frame and diffuser ring were merged together with an epoxy adhesive.

The LED-PCB was placed between front and backside with the LEDs directed to the front. Four wires (*GND*, *PWR*, *SDA*, and *SCL*) from the LED-PCB came out of the backside of the electric socket and were connected to the Arduino.

6.2.2 Software

The goal is to implement the visualizations *Rotation* and *Pulse* with the given hardware which is mainly a ring of 20 LEDs. The brightness of an LED can be changed via an Arduino command. The command consists of the specific LED driver address, an LED register for a specific LED, and the value of the brightness (between 0 and 255, where 0 means LED off and 255 means full brightness).

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[8] http://www.evonik.com

A timer interrupt starts the basic visualization routine every 10-30 ms and the purpose of the routine is to refresh the brightness of all LEDs. Meanwhile, the routine looks for a new data package from the *Data-Unit* all the time. With the information from the data package, the system changes the visualization into *Rotation*, *Pulse* or even turns it off. Additionally, the data for *Rotation* contains values for rotation speed and color.

For a better understanding the visualization routine is divided into two pieces, *Rotation Routine* and *Pulse Routine*.

The Rotation Routine

The *Rotation* visualization consists of two simple components. A luminescent spot which circles around the plug and a tail which follows the spot. Firstly, we recreated the rotating spot by a simple series of steps. A single LED turns on and after a while it turns off and the successor LED turns on. Again, the shining LED turned off and the successor turned on. This pattern repeats itself until the routine is interrupted by incoming data. The LED's on and off time describes the rotation speed. Until now this generates a flashing point which spins around the plug, but it is not smooth and very choppy. To get a fluid animation we add a fade-in and a fade-out mechanism to the on and off method. By extending the duration of the fade-out sequence, it is possible to add a tail which becomes longer when increasing the duration. These are the basic steps of building the *Rotation*. The chart in Figure 6.6 gives a good overview of them.

The program also has to calculate the color. That means it has to divide the color data into values for red, green and blue and it generates an array of brightness for each of them. An additional factor is the Gamma correction [SIGGRAPH, 2011] which balances the non-linearity of the LED light. This is also calculated into the array of brightness steps. It composes a colored luminescence by mixing the red, green, and blue diode of a single RGB LED by assigning the values of the predefined brightness array to the brightness of all sub-LEDs.

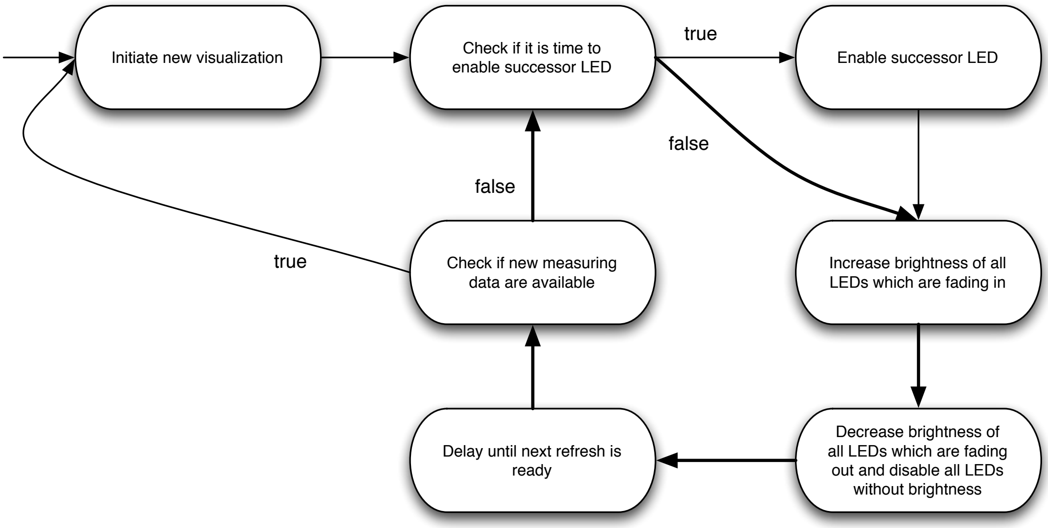


Figure 6.6: Rotation Routine - Step By Step

The Pulse Routine

In contrast to the *Rotation Routine* which controls each LED as a single object, the *Pulse Routine* manages the fade-in and the fade-out sequence for all LEDs at the same time. The *Pulse* visualization is always colored in green and has a fixed pulse frequency. That makes it possible to adapt the fading sequences of the *Rotation Routine* and run it with constant values.

6.3 The Mock-Up Wall

Additionally to our self made electric socket and the integrated LED-PCB, there are two microcontroller boards, a modified smart meter and a power adapter unit (see Figure 6.7). These parts are all necessary for the hardware prototype and it is best when they are collected in one box. This is the reason why we created the mock-up wall, which is a rectangular box with the measures of 220 mm x 150 mm x 400 mm (L x W x H) and ordinary white wallpaper. The self made solution of the electric socket was installed in a height of 230 mm in the middle of the front. All other parts were

Figure 6.7: Backside of the Mock-Up Wall: Microcontrollers, Power Adapter, Modified Smart Meter, Extension Cord, and Wires

integrated into the box and connected with each other. An extension cord was attached to the box, such that the mock-up wall could be plugged with an external electric socket. This supplies the hardware and the electrical device which is connected to the PowerSocket prototype with electricity.

6.4 Evaluation

6.4.1 Subjects

A user study with four male and four female subjects was conducted to evaluate the usage of the hardware prototype of PowerSocket. Their age varied between 23 and 33 years. Two participants were students, while other six were employees. Four out of eight subjects had a scientific or technical background.

6.4.2 User Study Design and Results

PowerSocket vs. PEM

In the design of the user test the PowerSocket with *Rotation* visualization (see Figure 6.3 was compared to a PEM (see Figure 1.1). The PEM was plugged in a wall socket near to the floor. Next to the PEM stood the hardware prototype. The subject sat two meters away from the setup on a chair. Four plugs of four appliances lay in front of the meters. The appliances are listed in Table 6.1—"Four Electrical Devices for all Power Consumption Category" and each represent a value of Table 5.1—"Sequence Settings". The interviewer sat not visible behind the subject.

Electrical Device	Power Consumption	Category	Rotation Speed	Color
Power Supply	0.5 W	Low	500 s/rev	green
Notebook	45-65 W	MidLow	7 s/rev	green-yellow
Vacuum Cleaner	400-500 W	MidHigh	0.8 s/rev	orange
Hair Dryer	1600 W	High	0.2 s/rev	red

Table 6.1: Four Electrical Devices for all Power Consumption Category

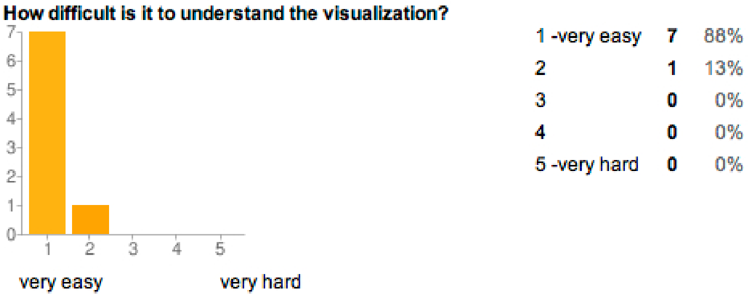
Part 1: PowerSocket in Comparison with a Personal Energy Meter

Design. The Subject got the instruction to plug the *MidLow* device in the PowerSocket prototype. Afterward, the subject had to estimate the power consumption by observing the visualization. Afterwards, the subject had to repeat the procedure with the PEM. Meanwhile the actions of the subject were observed and analyzed at a later point.

Furthermore, questions from Section 5.3.2—“Qualitative Study” were asked for booth cases.

Results. We definitely recognize a difference between reading the power consumption from the PowerSocket and the PEM. When the subjects plugged the device into the PowerSocket, they went back to their place. Whereas in the test with the PEM, the subjects (75%) came very close and knelt down to read from the display. One participant mentioned, ”I cannot figure it out at this distance, that’s not user-friendly”. We think it is an important finding, for instance old people would have a problem with the PEM because of their reduced eyesight and their constrained movement.

In the second section of part one the subjects answered that they are able to interpret the PowerSocket, but it was still hard to estimate the current power consumption (see Figure 6.8 and Figure 6.9). We assume that the user has to interact with the PowerSocket and different appliances regularly to learn the specific gradations of rotation speed, color, and device consumption.



1 -very easy	7	88%
2	1	13%
3	0	0%
4	0	0%
5 -very hard	0	0%

Figure 6.8: *Rotation* Question: Understanding

The appearance of the PowerSocket prototype was for every subject pleasant and not disturbing. In contrast, the subjects mentioned that the PEM is too big and unaesthetic as in this quote, ”It is too huge. Had each power socket in my household such a thing then I had everywhere such a brick.”.

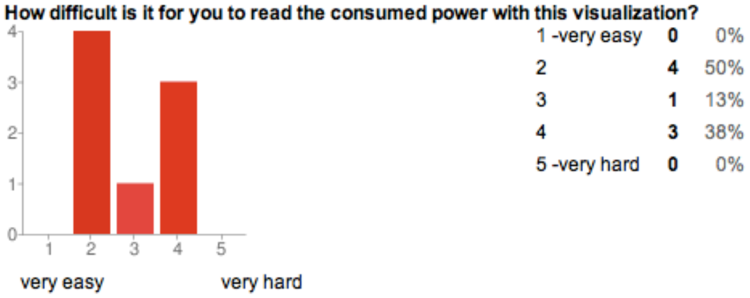


Figure 6.9: *Rotation* Question: Estimate Power Consumption

Part 2: PowerSocket and Four Electrical Devices

Design. There was a set of four electrical devices arranged from low to high energy consumption. Subjects had to perform the following tasks for each of them. The subject plugged a device in and the interviewer stated the estimated power consumption in Watt. Afterward, the subject had to answer the following questions: How much fits the visualization to the appliance and how the visualization appears. The answer was given as a rating in five steps between *very little* to *very much* and *comfortable* to *disturbing*.

Results. Altogether, the subjects rated for all four visualizations that their mapping of the devices were very good. Especially for the power supply with *Low* load a subject mentioned, ”It [PowerSocket] shows me that energy is consumed even there is nothing plugged in.” Only for the vacuum cleaner (*MidHigh*) two participants suggested to choose a red color with a higher contrast level.

The Appearance for the visualization of *Low*, *MidLow*, and *MidHigh* was rated as comfortable. The *High* consumption visualization built a exception because only 38% of the subjects decided that it is comfortable and the rest was undecided. ”I feel a little source of stress”, was noted by a participant. This is comprehensible because of the very high rotation speed and the intensive red luminescence. On the other hand, further subjects mentioned that this stress factor is necessary to realize the huge amount of power consumption, ”It rotates very fast, but that is alright.” and ”It is still comfortable enough that I don’t flip out, but it is stressful enough to force me to do something.”

Part 3: *Pulse* Visualization

Design. In the last part of our user study the *Pulse* visualization was tested. The subject watched the *Pulse* with a connected *Low* load device in this case the power supply. The subject had to assume what is the meaning of the visualization. Afterwards the interviewer explained that the *Pulse* visualize low power consumption (e.g., for devices in standby mode). The participant had to rate this solution in five steps from *very bad* to *very good*.

Results. More than the half of participants did not figure out the intention of the visualization. Many of them were confused and they mentioned things like ”That makes me crazy.” and ”The pulsation makes me insane.”

Afterward, the interviewer explained the intention of the *Pulse* and asked the subjects if it is a good or bad solution. Four subjects (50%) rated it is a very good solution, but three other participants rated it as a bad idea (see Figure 6.10).

1 -very bad	1	13%
2	1	13%
3	1	13%
4	0	0%
5 -very good	4	50%

Figure 6.10: Rating for *Pulse* Visualization

Suggestions

Two participants contributed improvements to the tested setup. One subject suggested to visualize the power consumption over a period of time. Another participant had the idea to integrate a dim functionality which reduce the brightness after a few seconds when there is no change in consumption and it gets full brightness when a change is recognized.

Chapter 7

Summary and future work

In the previous chapters we presented the idea and described the development process of our system PowerSocket. At last, we will give a summary of the most important aspects and the possible insights into the future.

7.1 Summary and contributions

PowerSocket is an ambient information system which is integrated into an electric socket and provides real-time feedback for power consumption of a plugged-in device. The system is divided into two components:

Data-Unit. This unit measures the current power consumption of a device which is plugged in. Furthermore, it converts the measuring data into values for rotation speed and color. Finally, the module sends the calculated data to the *Visualization-Unit*.

Visualization-Unit. With the information from the *Data-Unit* it creates the feedback visualization which consists of a luminescent spot which rotates around the plug in a circle. Speed and color describes the actual power consumption.

During the process we made some expressive steps:

1. In a public survey we asked about the power consumption behavior and knowledge of German households.
2. We recreated a taxonomy about ambient information systems and worked out a set of five visualization types (*Rotation*, *Pulse*, *Spin*, *Bar graph*, and *LCD*).
3. The first software prototype of PowerSocket was running on an Apple iPad and augmented by a fake electrical cord. Additionally, the software had the five visualization types implemented .
4. After the user study we decided to concentrate on the *Rotation* type and we built a hardware prototype with this visualization.

We started with an idea which was confirmed by the results of our public survey. The way through software and hardware prototypes gives a vision of the final version of PowerSocket and what is necessary to do.

7.2 Future work

In this chapter we will present ideas and suggestions which arose during the process of the thesis. As we concentrated on the basics of PowerSocket, the following states potential further research topics.

7.2.1 PowerSocket Network

A Power Line Communication (PLC) module integrated into the PowerSocket provides the capability to create a network of PowerSockets which communicate among each other. They can create clusters for rooms or specific parts of the house. Also, it is possible that they react and interpret measuring data from neighbor PowerSockets. Furthermore, all PowerSockets can communicate with a server where all the data runs together.

7.2.2 Smartphone and Desktop Application

As a further next step, the server can share the data via Wi-Fi with other devices or just with the cloud. For instance, a smartphone application like Wattbot [Petersen et al., 2009] can change the perception of energy consumption of the whole household. But in contrast to the approach by Petersen et al. [2009], the PowerSocket network can deliver very detailed information of the current wattage of each single electric device. Another point is the identification of the PowerSockets. With a unique luminescent sign which could be identified by the camera of the smartphone it would be possible to refer the socket to the value of the application.

7.2.3 Handy Version of PowerSocket

The hardware prototype is practical for a first insight of the capabilities of PowerSocket. However, in the future it will be necessary to make larger studies. Therefore, a handy and smaller version of PowerSocket is helpful. For studies in different households it is not practical to install the PowerSocket into the hole of the wall socket every time. It is probably a better solution to built a case like 'Kill-a-Watt' which can plugged into the existing socket.

7.2.4 Field Study

In our user study we figured out the differences between ordinary smart meters and the PowerSocket. Furthermore, the user test helps to define details in appearance and visualization. Nevertheless, the real effectiveness of PowerSocket and whether it helps to reduce power consumption or not will only be figured out in a field study with several households.

Appendix A

Visualization-Unit: Construction Drawing of the Self-Made Electric Socket

The initial construction drawing is part of the 3D CAD Model which was used to print the case of the hardware prototype of PowerSocket.

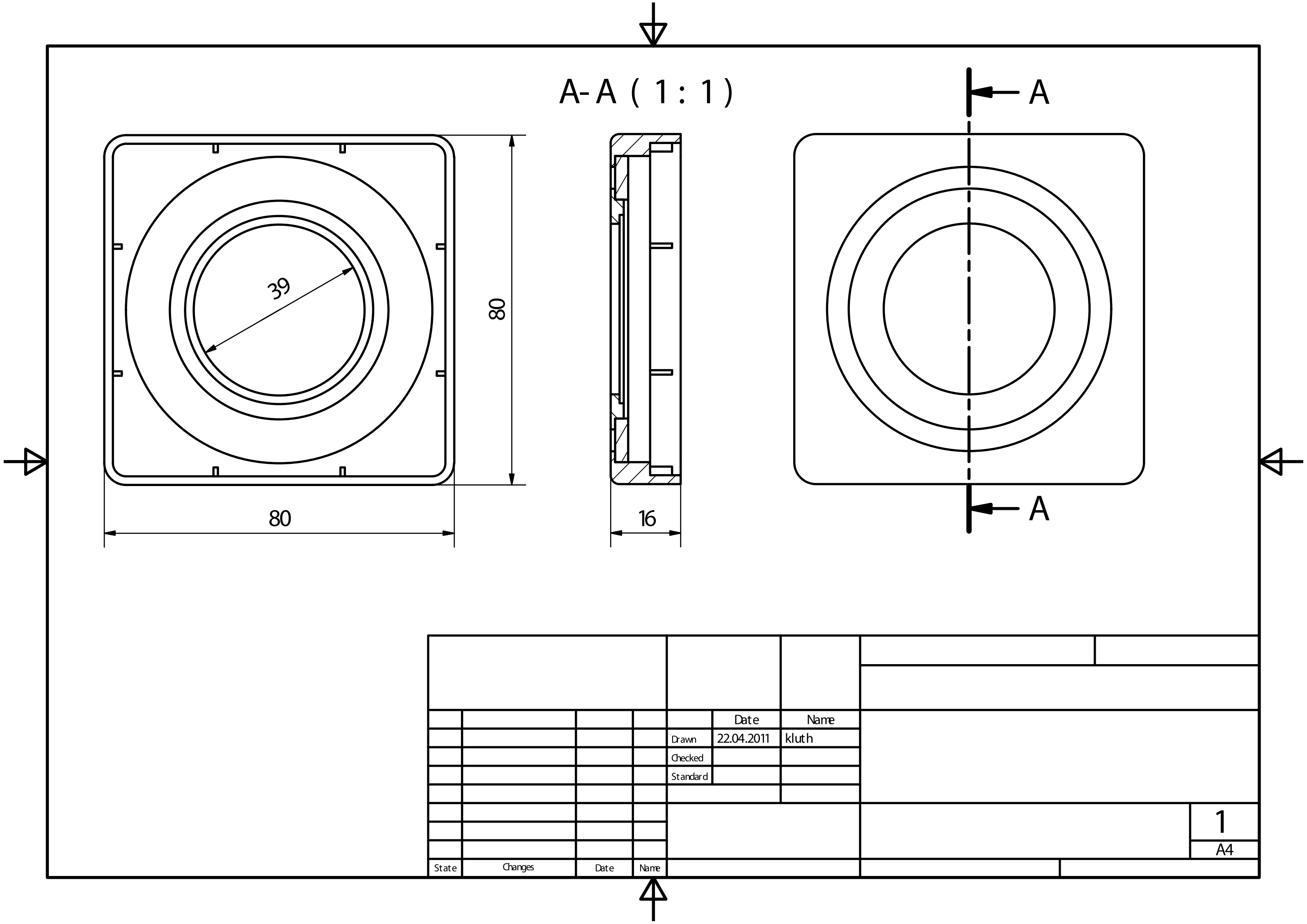


Figure A.1: Construction Drawing PowerSocket Case

Appendix B

Visualization-Unit: LED-PCB Schematic and Board Layout

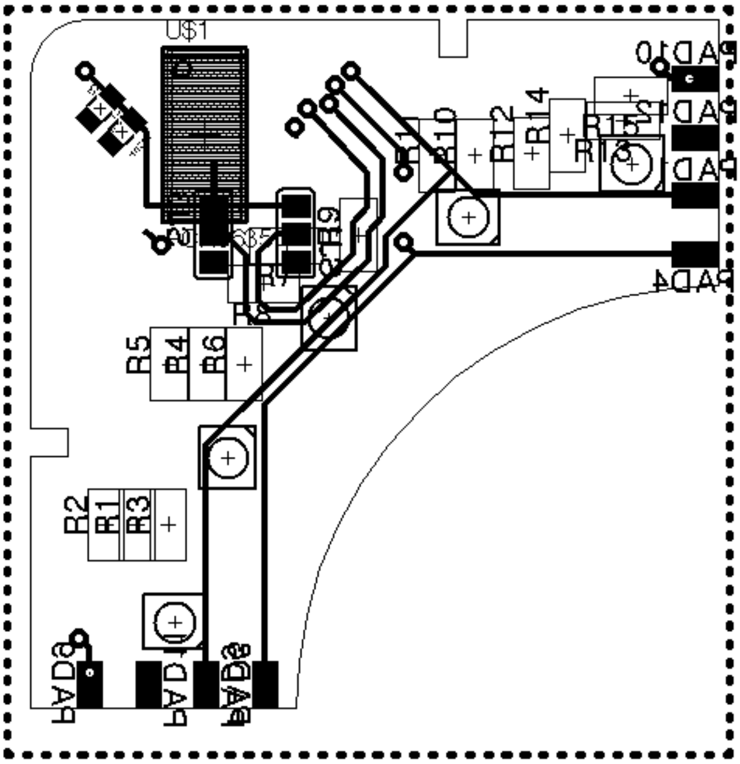


Figure B.1: Visualization-Unit: LED-PCB Board Layout

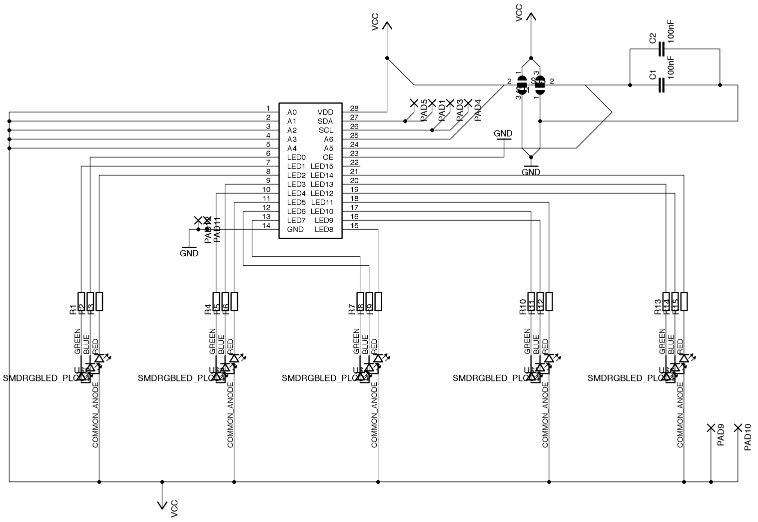


Figure B.2: Visualization-Unit: LED-PCB Schematic Layout

Appendix C

Visualization-Unit: Opto-Isolator Circuit Schematic and Board Layout

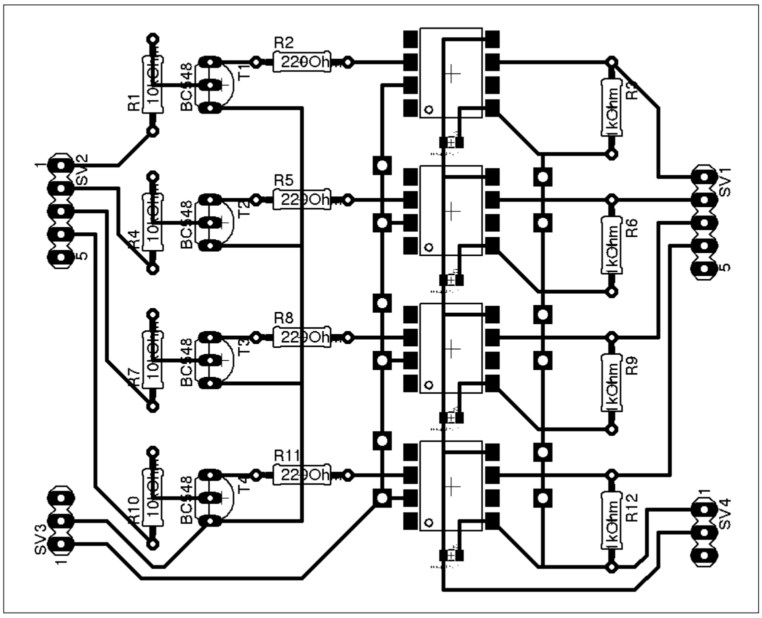


Figure C.1: Visualization-Unit: Opto-Isolator Circuit Board Layout

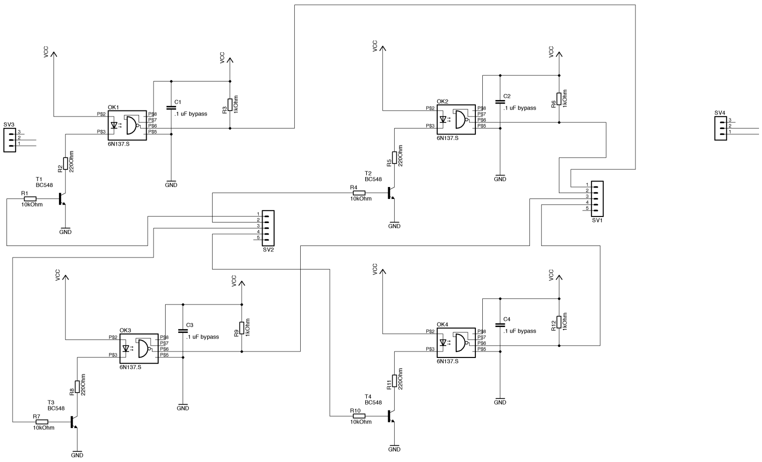


Figure C.2: Visualization-Unit: Opto-Isolator Circuit Schematic Layout

Appendix D

Survey: Power Consumption in German Households

The results of the survey were to extensive for publishing in the appendix. We decided to add a download link for the summary and the raw data.

File: Summary of the Survey Results (PDF)[a]

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[a] http://media.informatik.rwth-aachen.de/~kluth/thesis/PowerSocket-survey-summary.pdf

File: Raw Data of the Survey in Spreadsheet (CSV)[a]

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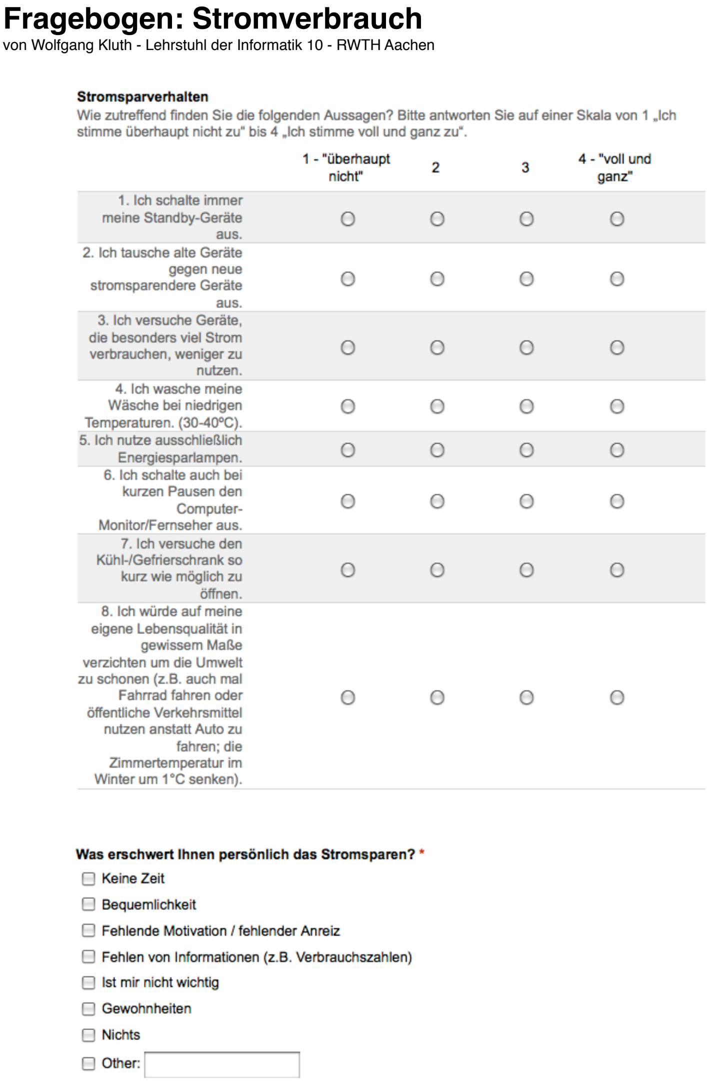
[a] http://media.informatik.rwth-aachen.de/~kluth/thesis/PowerSocket-survey.csv



Fragebogen: Stromverbrauch
von Wolfgang Kluth - Lehrstuhl der Informatik 10 - RWTH Aachen

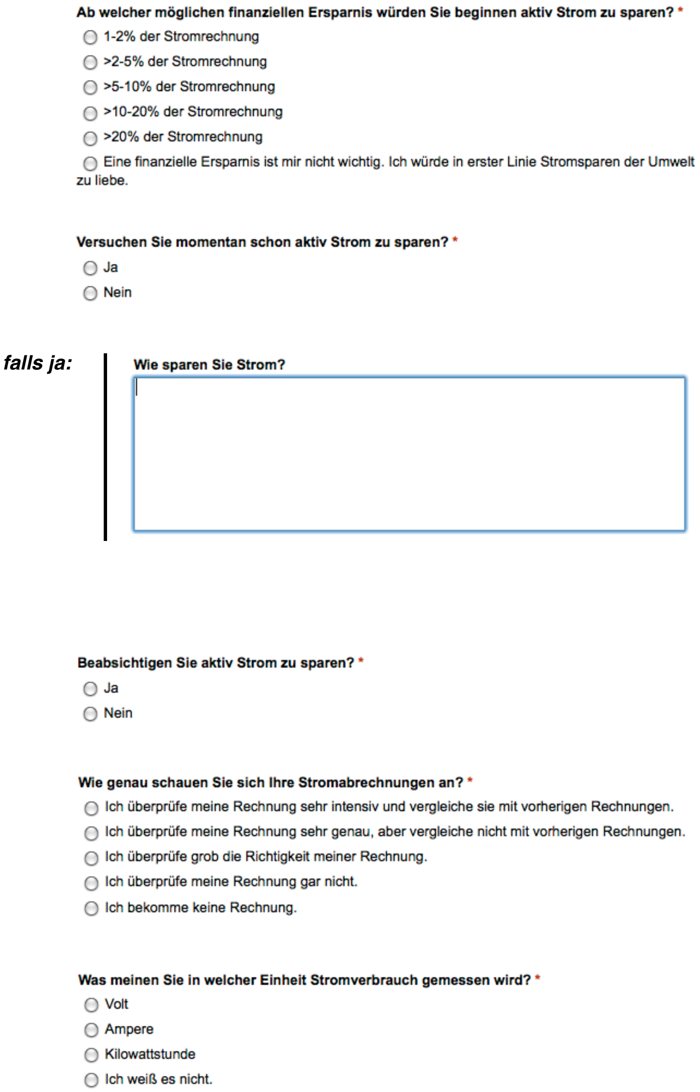
Stromsparverhalten
Wie zutreffend finden Sie die folgenden Aussagen? Bitte antworten Sie auf einer Skala von 1 „Ich stimme überhaupt nicht zu“ bis 4 „Ich stimme voll und ganz zu“.

	1 - "überhaupt nicht"	2	3	4 - "voll und ganz"
1. Ich schalte immer meine Standby-Geräte aus.	○	○	○	○
2. Ich tausche alte Geräte gegen neue stromsparendere Geräte aus.	○	○	○	○
3. Ich versuche Geräte, die besonders viel Strom verbrauchen, weniger zu nutzen.	○	○	○	○
4. Ich wasche meine Wäsche bei niedrigen Temperaturen. (30-40°C).	○	○	○	○
5. Ich nutze ausschließlich Energiesparlampen.	○	○	○	○
6. Ich schalte auch bei kurzen Pausen den Computer-Monitor/Fernseher aus.	○	○	○	○
7. Ich versuche den Kühl-/Gefrierschrank so kurz wie möglich zu öffnen.	○	○	○	○
8. Ich würde auf meine eigene Lebensqualität in gewissem Maße verzichten um die Umwelt zu schonen (z.B. auch mal Fahrrad fahren oder öffentliche Verkehrsmittel nutzen anstatt Auto zu fahren; die Zimmertemperatur im Winter um 1°C senken).	○	○	○	○

Was erschwert Ihnen persönlich das Stromsparen? *

☐ Keine Zeit
☐ Bequemlichkeit
☐ Fehlende Motivation / fehlender Anreiz
☐ Fehlen von Informationen (z.B. Verbrauchszahlen)
☐ Ist mir nicht wichtig
☐ Gewohnheiten
☐ Nichts
☐ Other:

Figure D.1: Survey Part 1: Power Consumption in German Households



Ab welcher möglichen finanziellen Ersparnis würden Sie beginnen aktiv Strom zu sparen? *

○ 1-2% der Stromrechnung
○ >2-5% der Stromrechnung
○ >5-10% der Stromrechnung
○ >10-20% der Stromrechnung
○ >20% der Stromrechnung
○ Eine finanzielle Ersparnis ist mir nicht wichtig. Ich würde in erster Linie Stromsparen der Umwelt zu liebe.

Versuchen Sie momentan schon aktiv Strom zu sparen? *

○ Ja
○ Nein

falls ja:

Wie sparen Sie Strom?

Beabsichtigen Sie aktiv Strom zu sparen? *

○ Ja
○ Nein

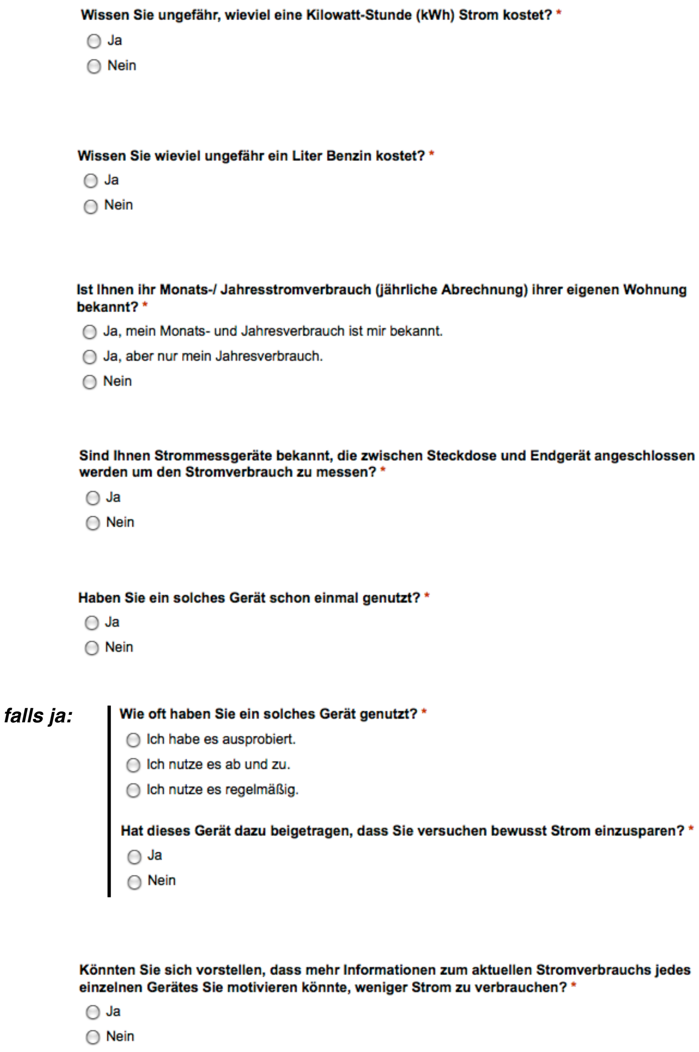
Wie genau schauen Sie sich Ihre Stromabrechnungen an? *

○ Ich überprüfe meine Rechnung sehr intensiv und vergleiche sie mit vorherigen Rechnungen.
○ Ich überprüfe meine Rechnung sehr genau, aber vergleiche nicht mit vorherigen Rechnungen.
○ Ich überprüfe grob die Richtigkeit meiner Rechnung.
○ Ich überprüfe meine Rechnung gar nicht.
○ Ich bekomme keine Rechnung.

Was meinen Sie in welcher Einheit Stromverbrauch gemessen wird? *

○ Volt
○ Ampere
○ Kilowattstunde
○ Ich weiß es nicht.

Figure D.2: Survey Part 2: Power Consumption in German Households



Wissen Sie ungefähr, wieviel eine Kilowatt-Stunde (kWh) Strom kostet? *

○ Ja
○ Nein

Wissen Sie wieviel ungefähr ein Liter Benzin kostet? *

○ Ja
○ Nein

Ist Ihnen ihr Monats-/ Jahresstromverbrauch (jährliche Abrechnung) ihrer eigenen Wohnung bekannt? *

○ Ja, mein Monats- und Jahresverbrauch ist mir bekannt.
○ Ja, aber nur mein Jahresverbrauch.
○ Nein

Sind Ihnen Strommessgeräte bekannt, die zwischen Steckdose und Endgerät angeschlossen werden um den Stromverbrauch zu messen? *

○ Ja
○ Nein

Haben Sie ein solches Gerät schon einmal genutzt? *

○ Ja
○ Nein

falls ja:

Wie oft haben Sie ein solches Gerät genutzt? *

○ Ich habe es ausprobiert.
○ Ich nutze es ab und zu.
○ Ich nutze es regelmäßig.

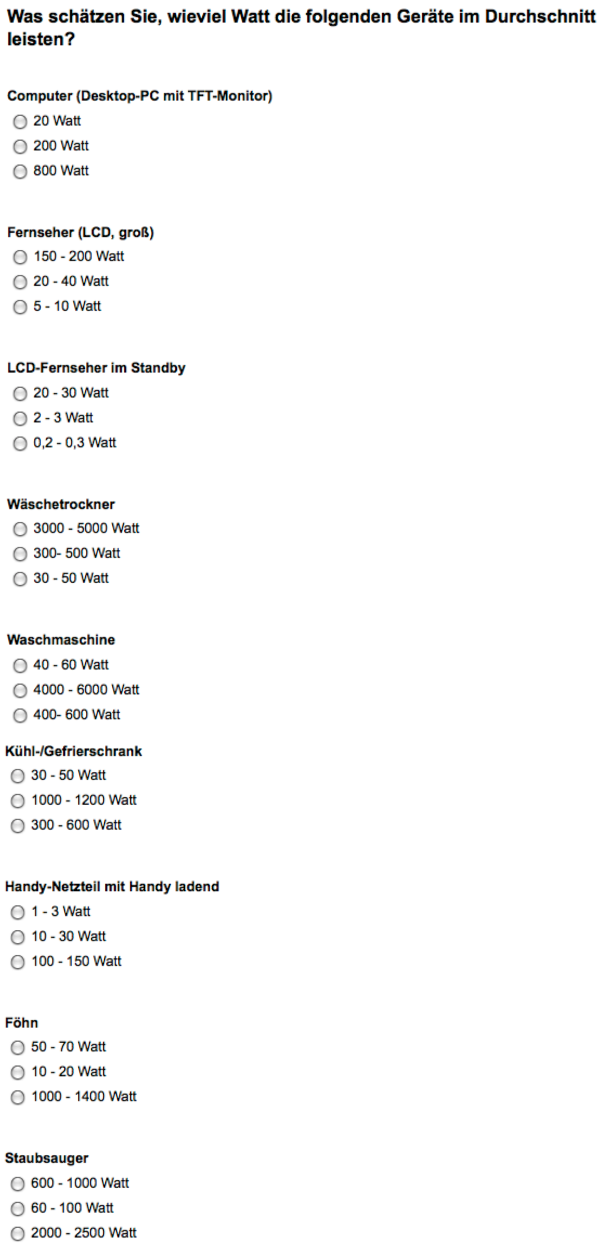
Hat dieses Gerät dazu beigetragen, dass Sie versuchen bewusst Strom einzusparen? *

○ Ja
○ Nein

Könnten Sie sich vorstellen, dass mehr Informationen zum aktuellen Stromverbrauchs jedes einzelnen Gerätes Sie motivieren könnte, weniger Strom zu verbrauchen? *

○ Ja
○ Nein

Figure D.3: Survey Part 3: Power Consumption in German Households



Was schätzen Sie, wieviel Watt die folgenden Geräte im Durchschnitt leisten?

Computer (Desktop-PC mit TFT-Monitor)
○ 20 Watt
○ 200 Watt
○ 800 Watt

Fernseher (LCD, groß)
○ 150 - 200 Watt
○ 20 - 40 Watt
○ 5 - 10 Watt

LCD-Fernseher im Standby
○ 20 - 30 Watt
○ 2 - 3 Watt
○ 0,2 - 0,3 Watt

Wäschetrockner
○ 3000 - 5000 Watt
○ 300- 500 Watt
○ 30 - 50 Watt

Waschmaschine
○ 40 - 60 Watt
○ 4000 - 6000 Watt
○ 400- 600 Watt

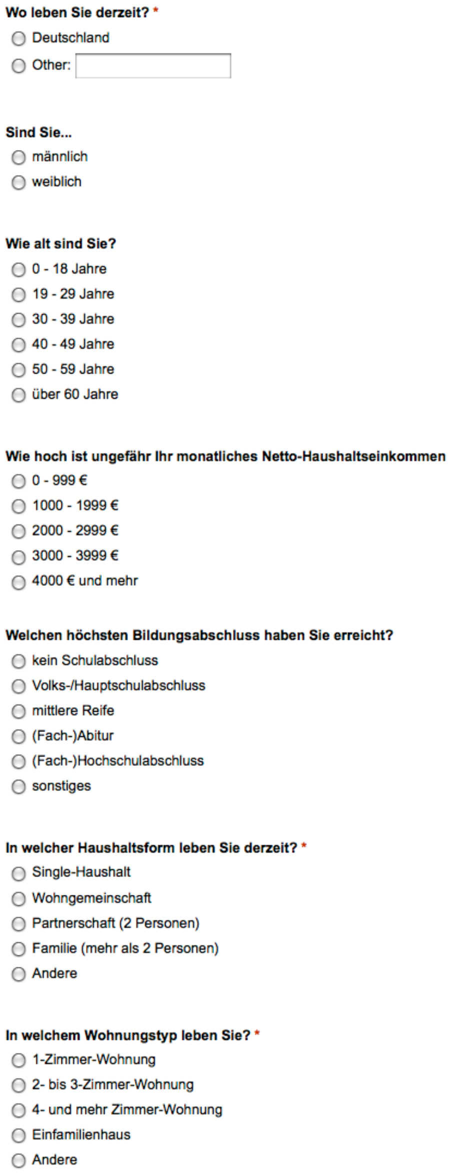
Kühl-/Gefrierschrank
○ 30 - 50 Watt
○ 1000 - 1200 Watt
○ 300 - 600 Watt

Handy-Netzteil mit Handy ladend
○ 1 - 3 Watt
○ 10 - 30 Watt
○ 100 - 150 Watt

Föhn
○ 50 - 70 Watt
○ 10 - 20 Watt
○ 1000 - 1400 Watt

Staubsauger
○ 600 - 1000 Watt
○ 60 - 100 Watt
○ 2000 - 2500 Watt

Figure D.4: Survey Part 4: Power Consumption in German Households



Wo leben Sie derzeit? *

○ Deutschland
○ Other: ☐

Sind Sie...

○ männlich
○ weiblich

Wie alt sind Sie?

○ 0 - 18 Jahre
○ 19 - 29 Jahre
○ 30 - 39 Jahre
○ 40 - 49 Jahre
○ 50 - 59 Jahre
○ über 60 Jahre

Wie hoch ist ungefähr Ihr monatliches Netto-Haushaltseinkommen

○ 0 - 999 €
○ 1000 - 1999 €
○ 2000 - 2999 €
○ 3000 - 3999 €
○ 4000 € und mehr

Welchen höchsten Bildungsabschluss haben Sie erreicht?

○ kein Schulabschluss
○ Volks-/Hauptschulabschluss
○ mittlere Reife
○ (Fach-)Abitur
○ (Fach-)Hochschulabschluss
○ sonstiges

In welcher Haushaltsform leben Sie derzeit? *

○ Single-Haushalt
○ Wohngemeinschaft
○ Partnerschaft (2 Personen)
○ Familie (mehr als 2 Personen)
○ Andere

In welchem Wohnungstyp leben Sie? *

○ 1-Zimmer-Wohnung
○ 2- bis 3-Zimmer-Wohnung
○ 4- und mehr Zimmer-Wohnung
○ Einfamilienhaus
○ Andere

Figure D.5: Survey Part 5: Power Consumption in German Households

Appendix E

User Study: Software Prototype

The results of the user study for the software prototype were to extensive for publishing in the appendix. We decided to add a download link for the summary and the raw data.

File: Summary of the User Study for the Software Prototype Results (PDF)[a]

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[a] http://media.informatik.rwth-aachen.de/~kluth/thesis/PowerSocket-userstudy-s-summary.pdf

File: Raw Data of the User Study for the Software Prototype in Spreadsheet (CSV)[a]

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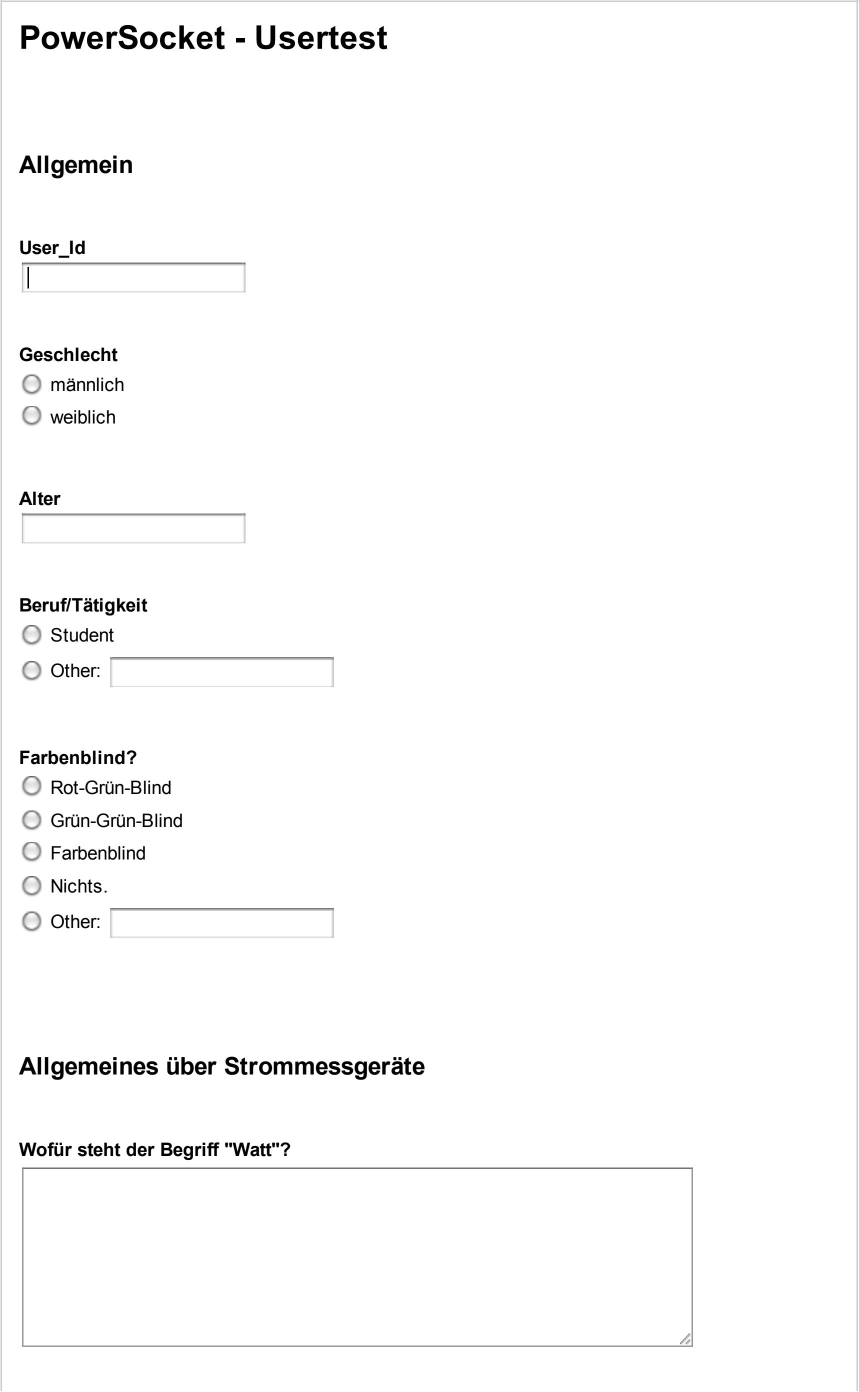
[a] http://media.informatik.rwth-aachen.de/~kluth/thesis/PowerSocket-userstudy-s.csv



PowerSocket - Usertest

Allgemein

User_Id

Geschlecht
○ männlich
○ weiblich

Alter

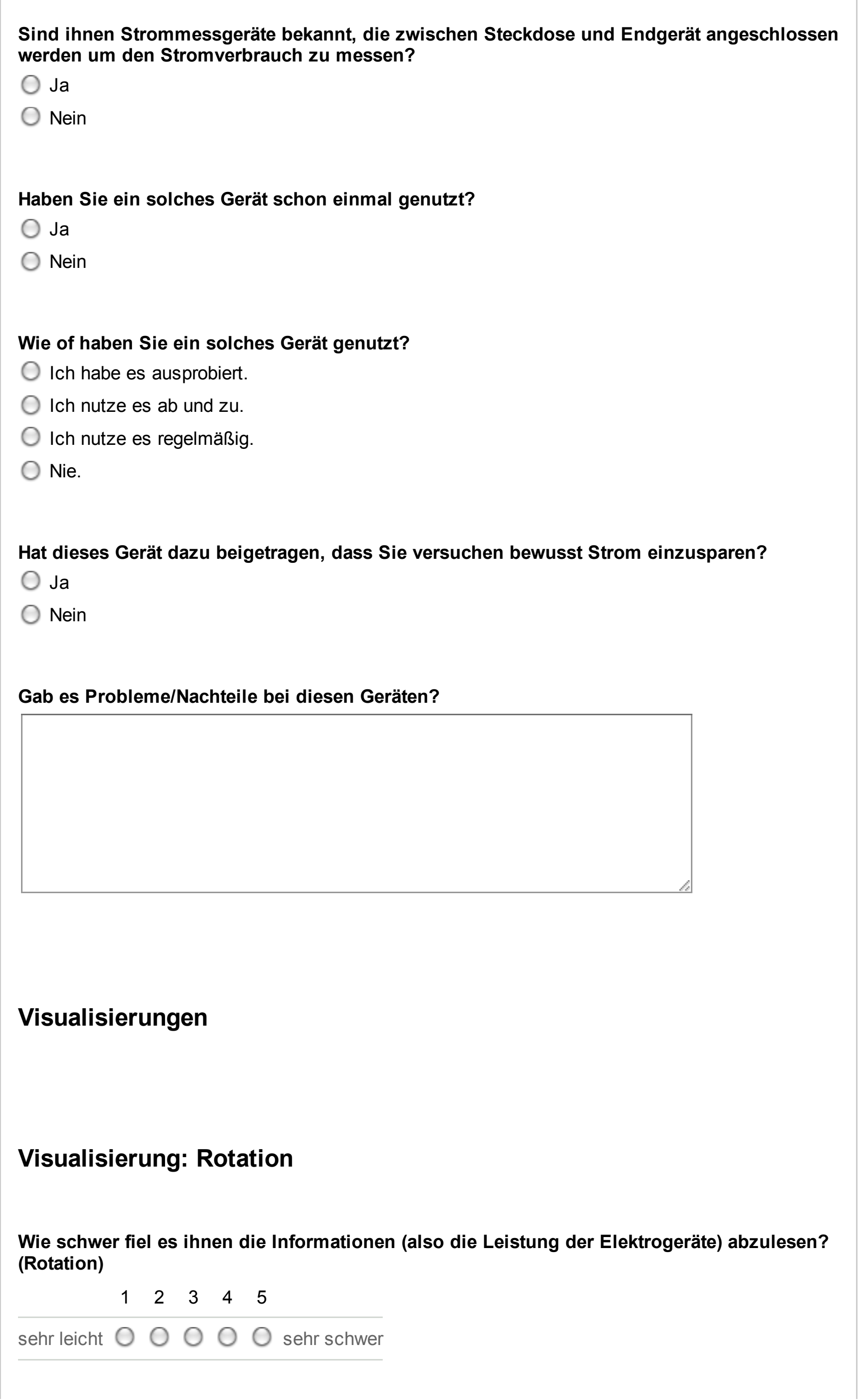
Beruf/Tätigkeit
○ Student
○ Other:

Farbenblind?
○ Rot-Grün-Blind
○ Grün-Grün-Blind
○ Farbenblind
○ Nichts.
○ Other:

Allgemeines über Strommessgeräte

Wofür steht der Begriff "Watt"?

Figure E.1: User Study Part 1: Software Prototype



Sind ihnen Strommessgeräte bekannt, die zwischen Steckdose und Endgerät angeschlossen werden um den Stromverbrauch zu messen?

○ Ja
○ Nein

Haben Sie ein solches Gerät schon einmal genutzt?

○ Ja
○ Nein

Wie of haben Sie ein solches Gerät genutzt?

○ Ich habe es ausprobiert.
○ Ich nutze es ab und zu.
○ Ich nutze es regelmäßig.
○ Nie.

Hat dieses Gerät dazu beigetragen, dass Sie versuchen bewusst Strom einzusparen?

○ Ja
○ Nein

Gab es Probleme/Nachteile bei diesen Geräten?

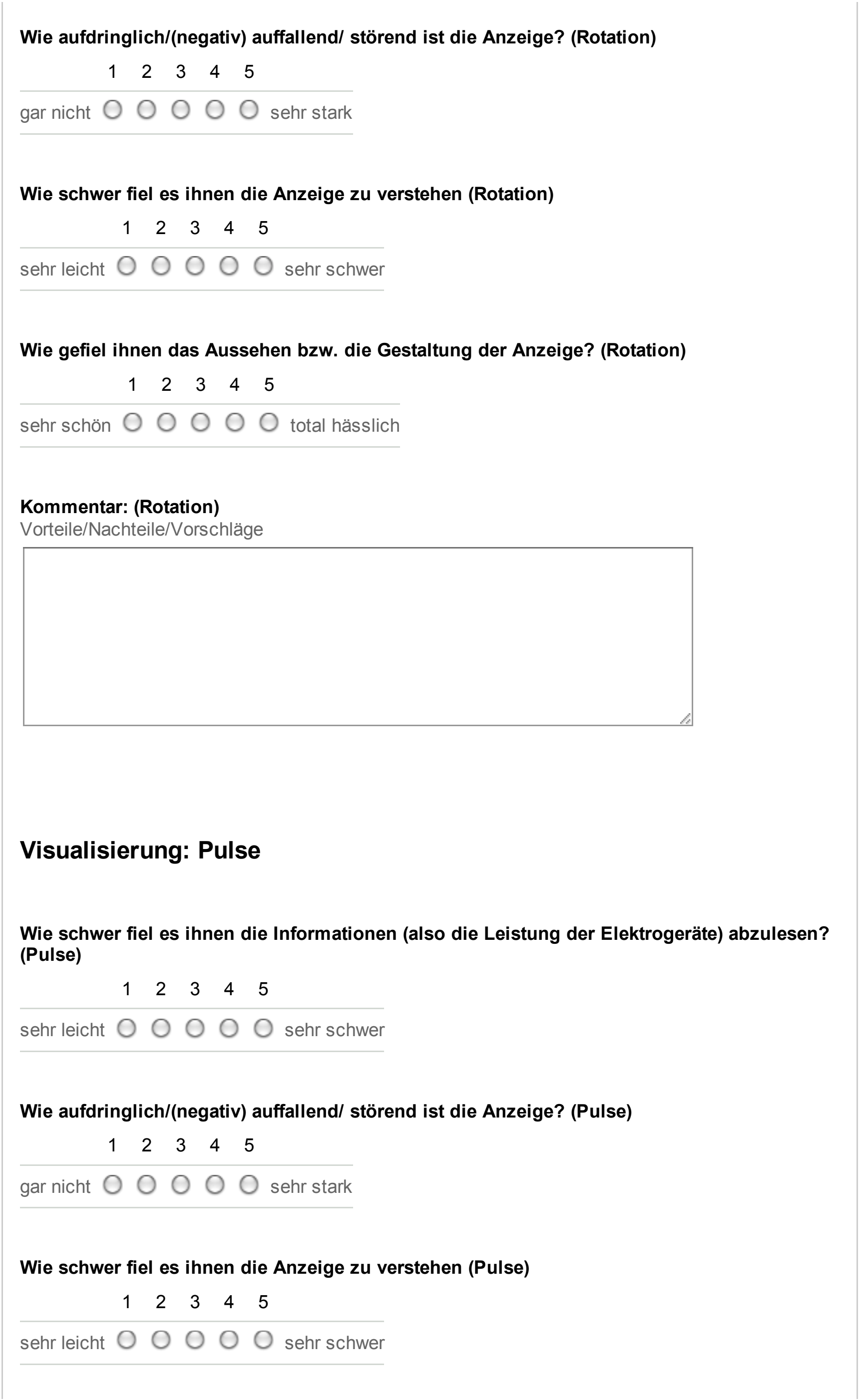
Visualisierungen

Visualisierung: Rotation

Wie schwer fiel es ihnen die Informationen (also die Leistung der Elektrogeräte) abzulesen? (Rotation)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Figure E.2: User Study Part 2: Software Prototype



Wie aufdringlich/(negativ) auffallend/ störend ist die Anzeige? (Rotation)

	1	2	3	4	5	
gar nicht	○	○	○	○	○	sehr stark

Wie schwer fiel es ihnen die Anzeige zu verstehen (Rotation)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Wie gefiel ihnen das Aussehen bzw. die Gestaltung der Anzeige? (Rotation)

	1	2	3	4	5	
sehr schön	○	○	○	○	○	total hässlich

Kommentar: (Rotation)
Vorteile/Nachteile/Vorschläge

Visualisierung: Pulse

Wie schwer fiel es ihnen die Informationen (also die Leistung der Elektrogeräte) abzulesen? (Pulse)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

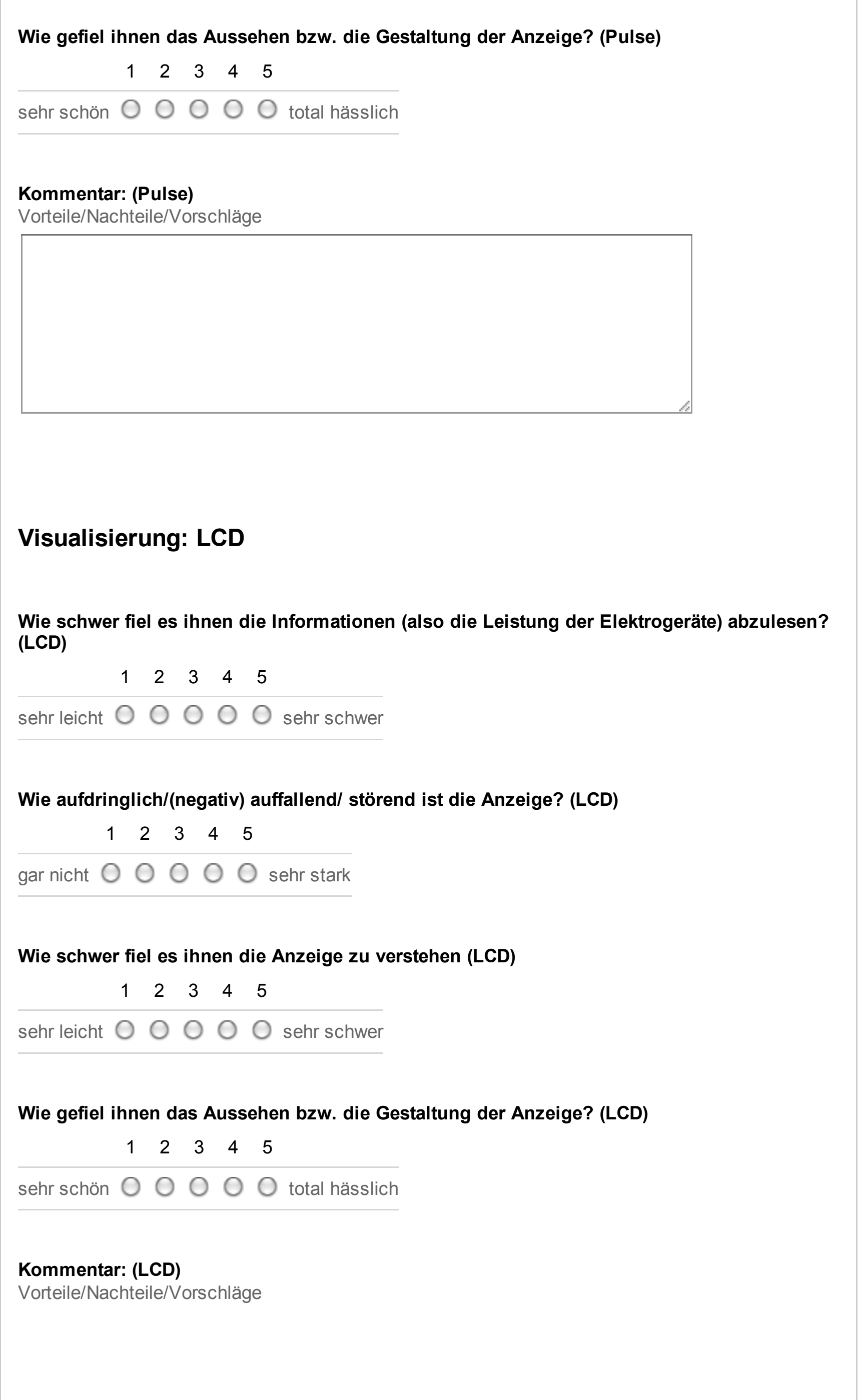
Wie aufdringlich/(negativ) auffallend/ störend ist die Anzeige? (Pulse)

	1	2	3	4	5	
gar nicht	○	○	○	○	○	sehr stark

Wie schwer fiel es ihnen die Anzeige zu verstehen (Pulse)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Figure E.3: User Study Part 3: Software Prototype



Wie gefiel ihnen das Aussehen bzw. die Gestaltung der Anzeige? (Pulse)

	1	2	3	4	5	
sehr schön	○	○	○	○	○	total hässlich

Kommentar: (Pulse)
Vorteile/Nachteile/Vorschläge

Visualisierung: LCD

Wie schwer fiel es ihnen die Informationen (also die Leistung der Elektrogeräte) abzulesen? (LCD)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Wie aufdringlich/(negativ) auffallend/ störend ist die Anzeige? (LCD)

	1	2	3	4	5	
gar nicht	○	○	○	○	○	sehr stark

Wie schwer fiel es ihnen die Anzeige zu verstehen (LCD)

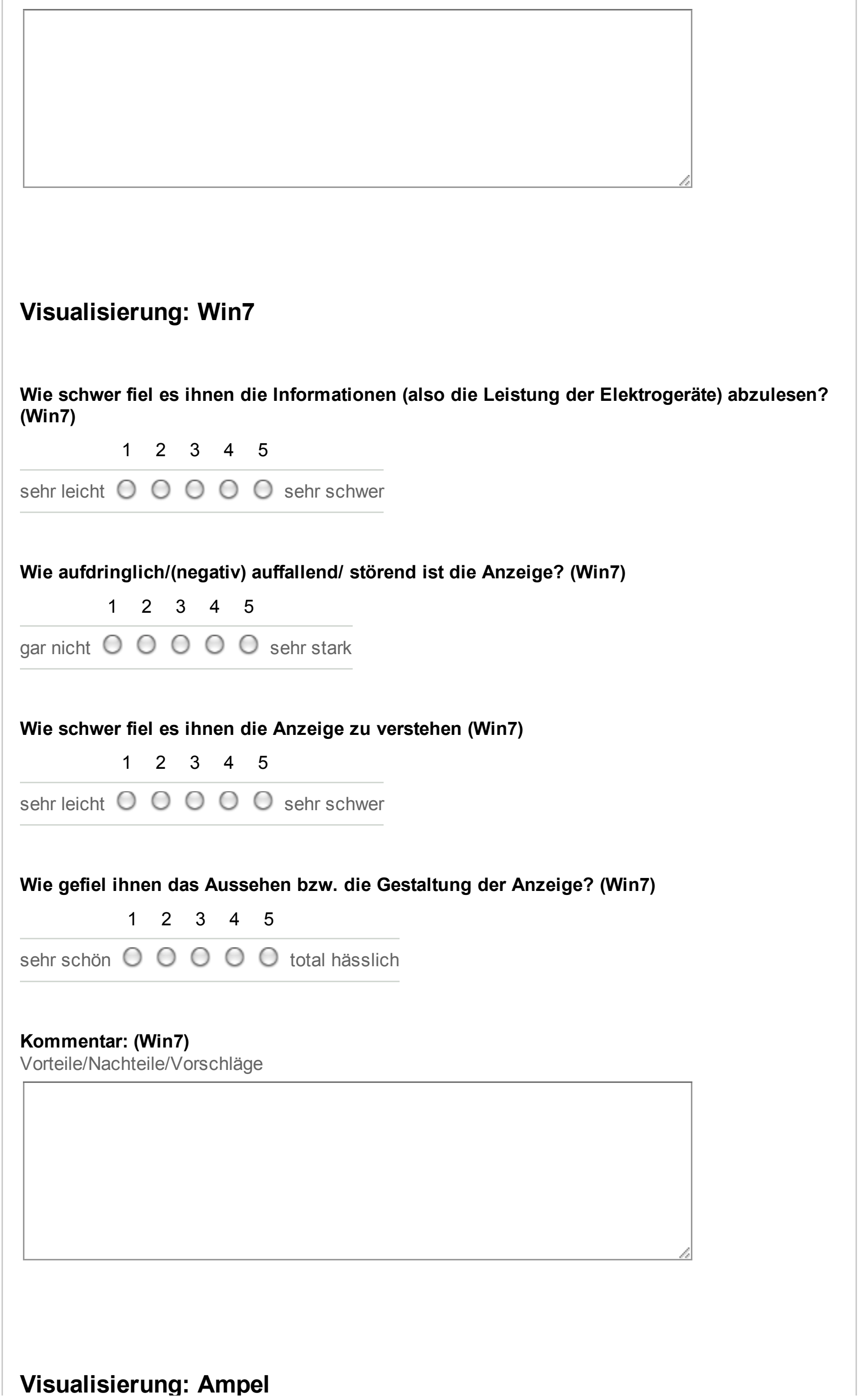
	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Wie gefiel ihnen das Aussehen bzw. die Gestaltung der Anzeige? (LCD)

	1	2	3	4	5	
sehr schön	○	○	○	○	○	total hässlich

Kommentar: (LCD)
Vorteile/Nachteile/Vorschläge

Figure E.4: User Study Part 4: Software Prototype



Visualisierung: Win7

Wie schwer fiel es ihnen die Informationen (also die Leistung der Elektrogeräte) abzulesen? (Win7)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Wie aufdringlich/(negativ) auffallend/ störend ist die Anzeige? (Win7)

	1	2	3	4	5	
gar nicht	○	○	○	○	○	sehr stark

Wie schwer fiel es ihnen die Anzeige zu verstehen (Win7)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Wie gefiel ihnen das Aussehen bzw. die Gestaltung der Anzeige? (Win7)

	1	2	3	4	5	
sehr schön	○	○	○	○	○	total hässlich

Kommentar: (Win7)
Vorteile/Nachteile/Vorschläge

Visualisierung: Ampel

Figure E.5: User Study Part 5: Software Prototype

Wie schwer fiel es ihnen die Informationen (also die Leistung der Elektrogeräte) abzulesen? (Ampel)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Wie aufdringlich/(negativ) auffallend/ störend ist die Anzeige? (Ampel)

	1	2	3	4	5	
gar nicht	○	○	○	○	○	sehr stark

Wie schwer fiel es ihnen die Anzeige zu verstehen (Ampel)

	1	2	3	4	5	
sehr leicht	○	○	○	○	○	sehr schwer

Wie gefiel ihnen das Aussehen bzw. die Gestaltung der Anzeige? (Ampel)

	1	2	3	4	5	
sehr schön	○	○	○	○	○	total hässlich

Kommentar: (Ampel)
Vorteile/Nachteile/Vorschläge

Ende

End-Kommentare

Figure E.6: User Study Part 6: Software Prototype

Appendix F

User Study: Hardware Prototype

The results of the user study for the hardware prototype were to extensive for publishing in the appendix. We decided to add a download link for the summary and the raw data.

File: Summary of the User Study for the Hardware Prototype Results (PDF)[a]

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[a] http://media.informatik.rwth-aachen.de/~kluth/thesis/PowerSocket-userstudy-h-summary.pdf

File: Raw Data of the User Study for the Hardware Prototype in Spreadsheet (CSV)[a]

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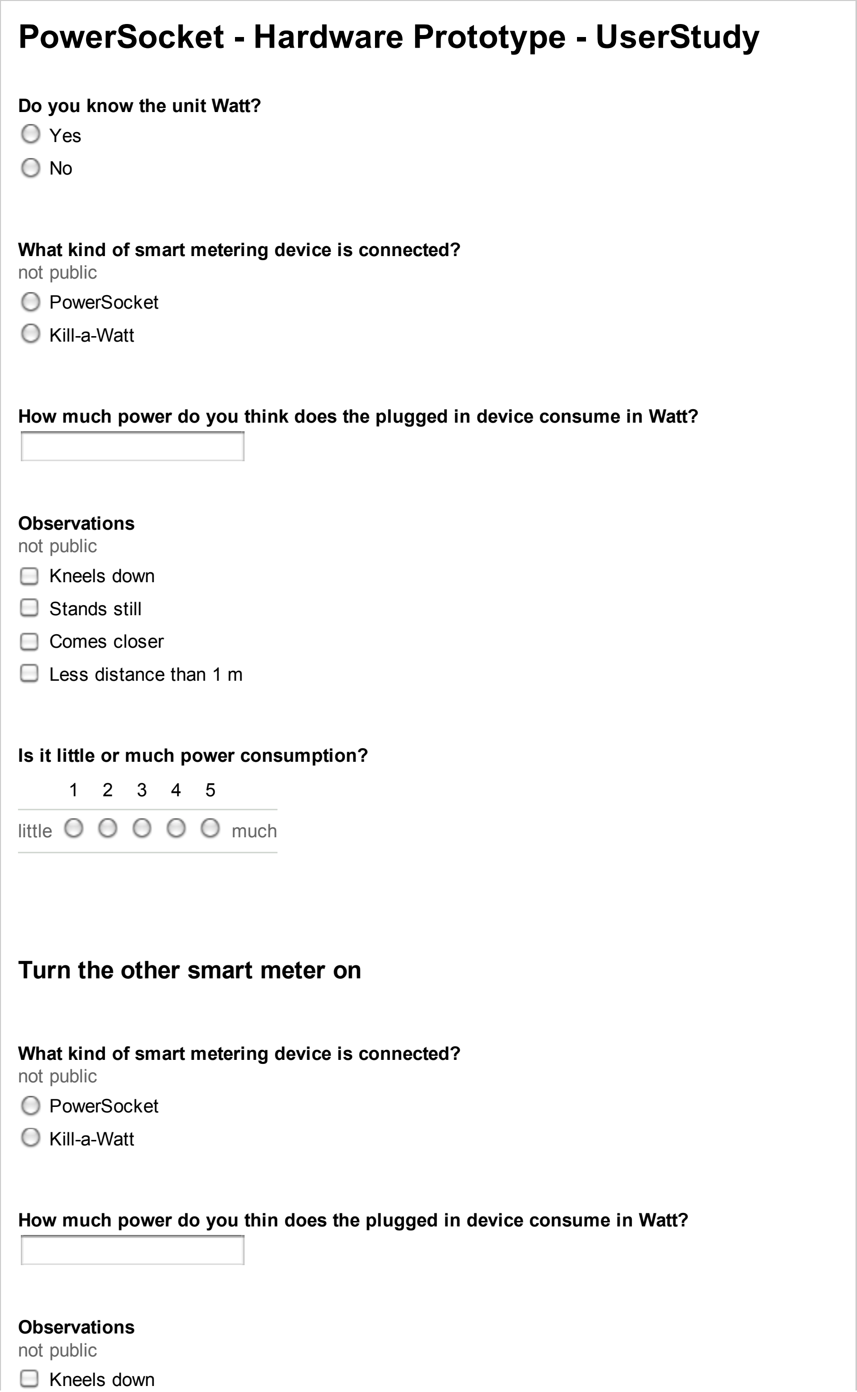
[a] http://media.informatik.rwth-aachen.de/~kluth/thesis/PowerSocket-userstudy-h.csv



PowerSocket - Hardware Prototype - UserStudy

Do you know the unit Watt?

○ Yes
○ No

What kind of smart metering device is connected?
not public

○ PowerSocket
○ Kill-a-Watt

How much power do you think does the plugged in device consume in Watt?

Observations
not public

☐ Kneels down
☐ Stands still
☐ Comes closer
☐ Less distance than 1 m

Is it little or much power consumption?

	1	2	3	4	5	
little	○	○	○	○	○	much

Turn the other smart meter on

What kind of smart metering device is connected?
not public

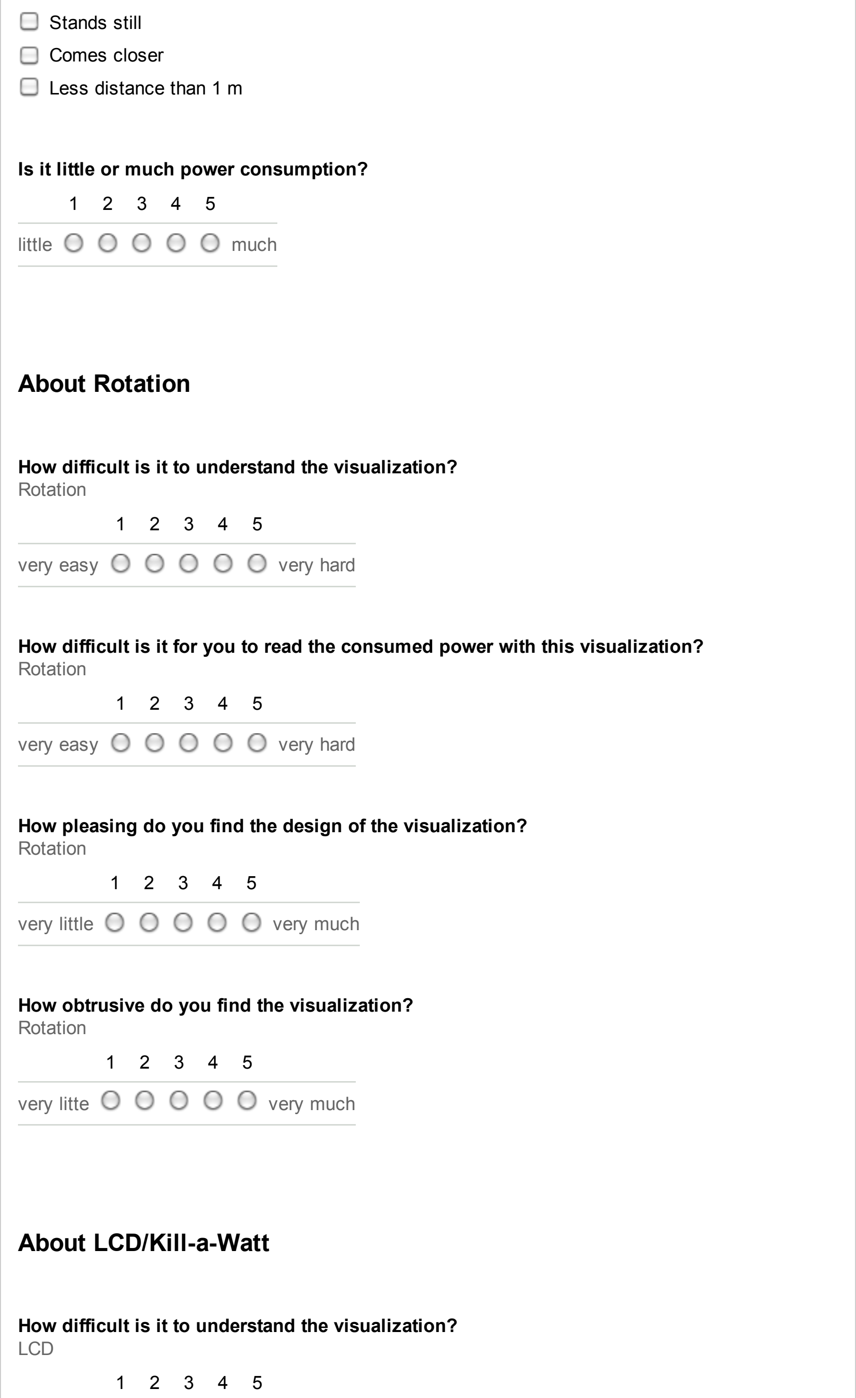
○ PowerSocket
○ Kill-a-Watt

How much power do you thin does the plugged in device consume in Watt?

Observations
not public

☐ Kneels down

Figure F.1: User Study Part 1: Hardware Prototype



☐ Stands still
☐ Comes closer
☐ Less distance than 1 m

Is it little or much power consumption?

	1	2	3	4	5	
little	○	○	○	○	○	much

About Rotation

How difficult is it to understand the visualization?
Rotation

	1	2	3	4	5	
very easy	○	○	○	○	○	very hard

How difficult is it for you to read the consumed power with this visualization?
Rotation

	1	2	3	4	5	
very easy	○	○	○	○	○	very hard

How pleasing do you find the design of the visualization?
Rotation

	1	2	3	4	5	
very little	○	○	○	○	○	very much

How obtrusive do you find the visualization?
Rotation

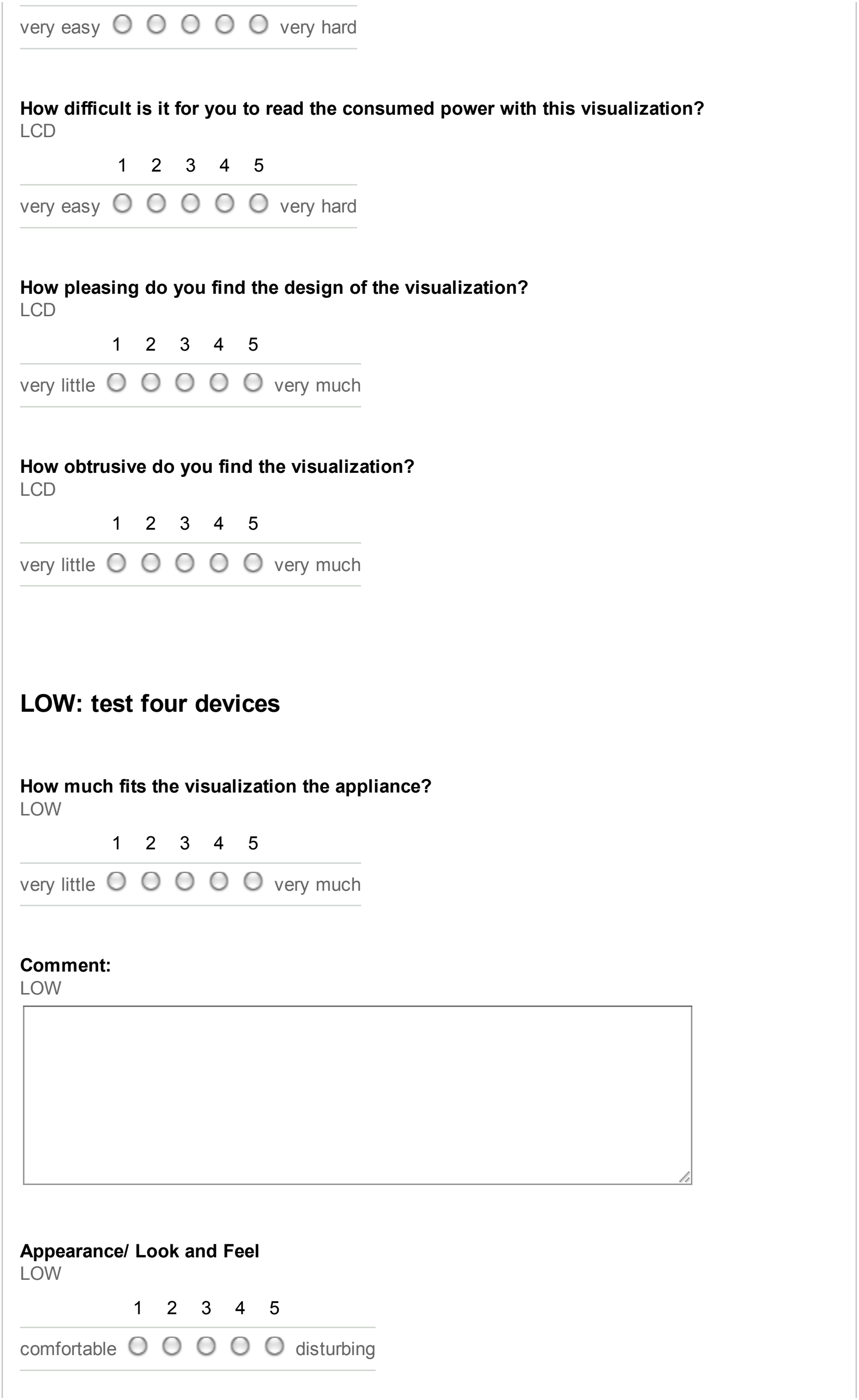
	1	2	3	4	5	
very litte	○	○	○	○	○	very much

About LCD/Kill-a-Watt

How difficult is it to understand the visualization?
LCD

	1	2	3	4	5	

Figure F.2: User Study Part 2: Hardware Prototype



very easy	○	○	○	○	○	very hard

How difficult is it for you to read the consumed power with this visualization?
LCD

	1	2	3	4	5	
very easy	○	○	○	○	○	very hard

How pleasing do you find the design of the visualization?
LCD

	1	2	3	4	5	
very little	○	○	○	○	○	very much

How obtrusive do you find the visualization?
LCD

	1	2	3	4	5	
very little	○	○	○	○	○	very much

LOW: test four devices

How much fits the visualization the appliance?
LOW

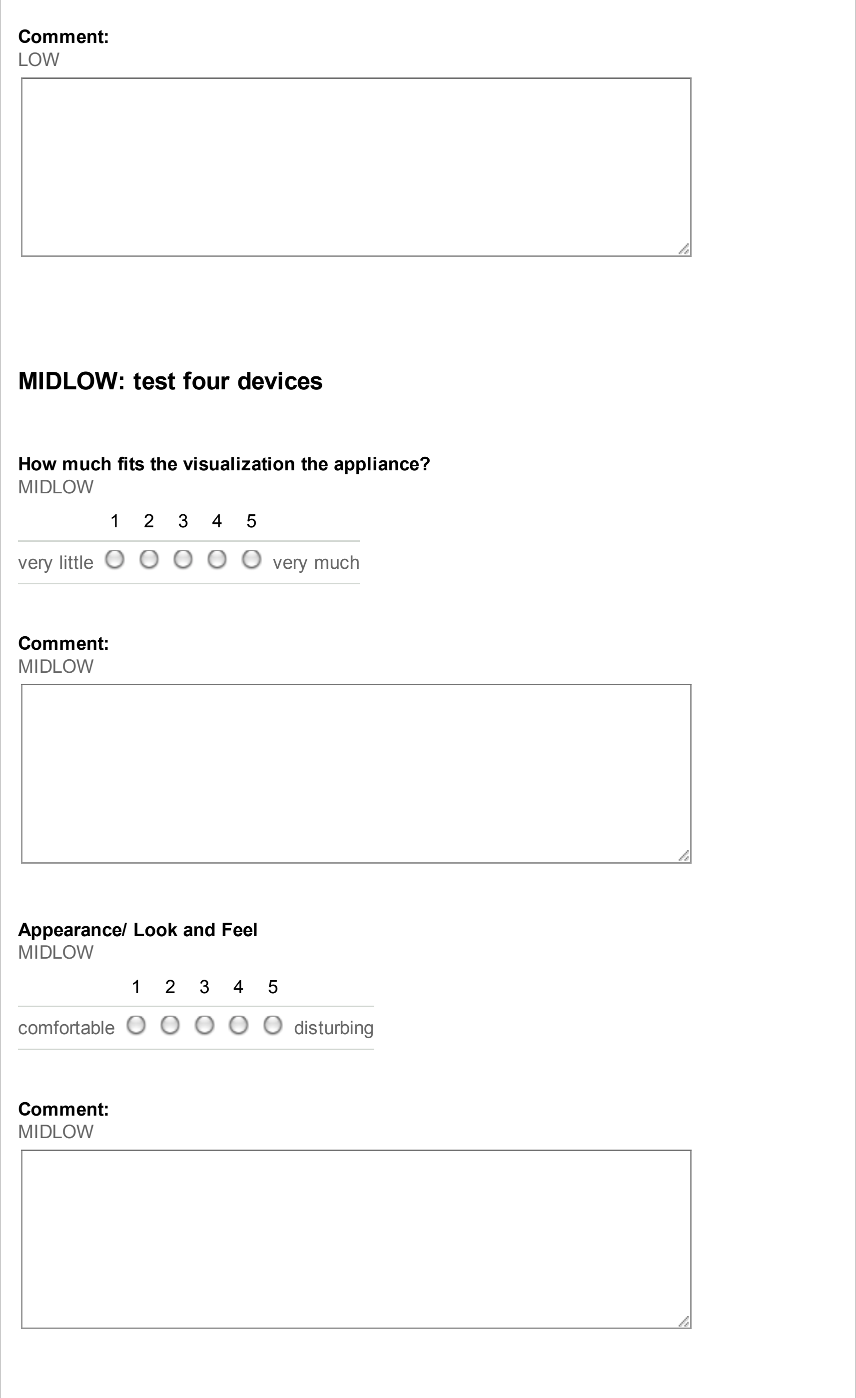
	1	2	3	4	5	
very little	○	○	○	○	○	very much

Comment:
LOW

Appearance/ Look and Feel
LOW

	1	2	3	4	5	
comfortable	○	○	○	○	○	disturbing

Figure F.3: User Study Part 3: Hardware Prototype



Comment:
LOW

MIDLOW: test four devices

How much fits the visualization the appliance?
MIDLOW

	1	2	3	4	5	
very little	○	○	○	○	○	very much

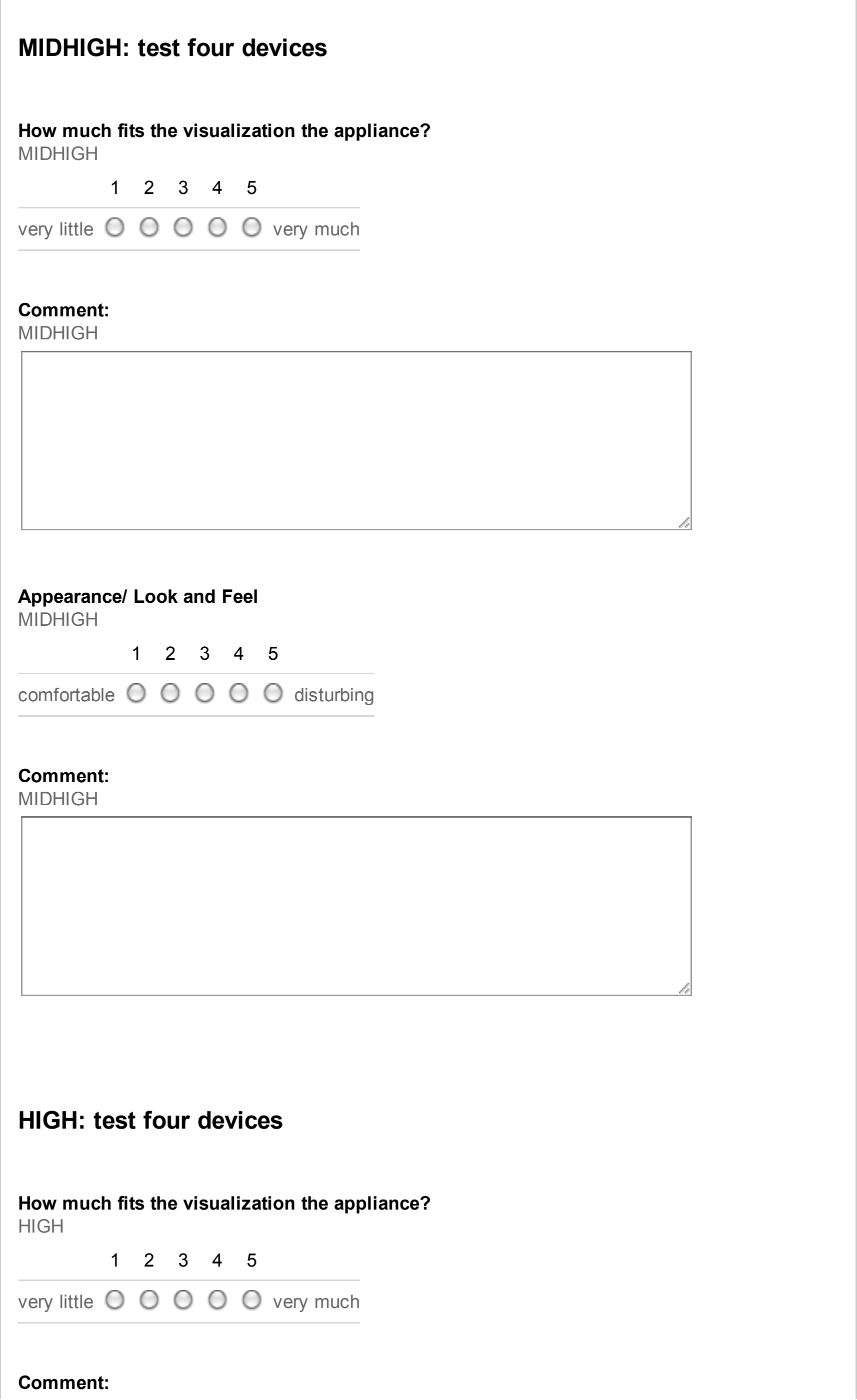
Comment:
MIDLOW

Appearance/ Look and Feel
MIDLOW

	1	2	3	4	5	
comfortable	○	○	○	○	○	disturbing

Comment:
MIDLOW

Figure F.4: User Study Part 4: Hardware Prototype



MIDHIGH: test four devices

How much fits the visualization the appliance?
MIDHIGH

	1	2	3	4	5	
very little	○	○	○	○	○	very much

Comment:
MIDHIGH

Appearance/ Look and Feel
MIDHIGH

	1	2	3	4	5	
comfortable	○	○	○	○	○	disturbing

Comment:
MIDHIGH

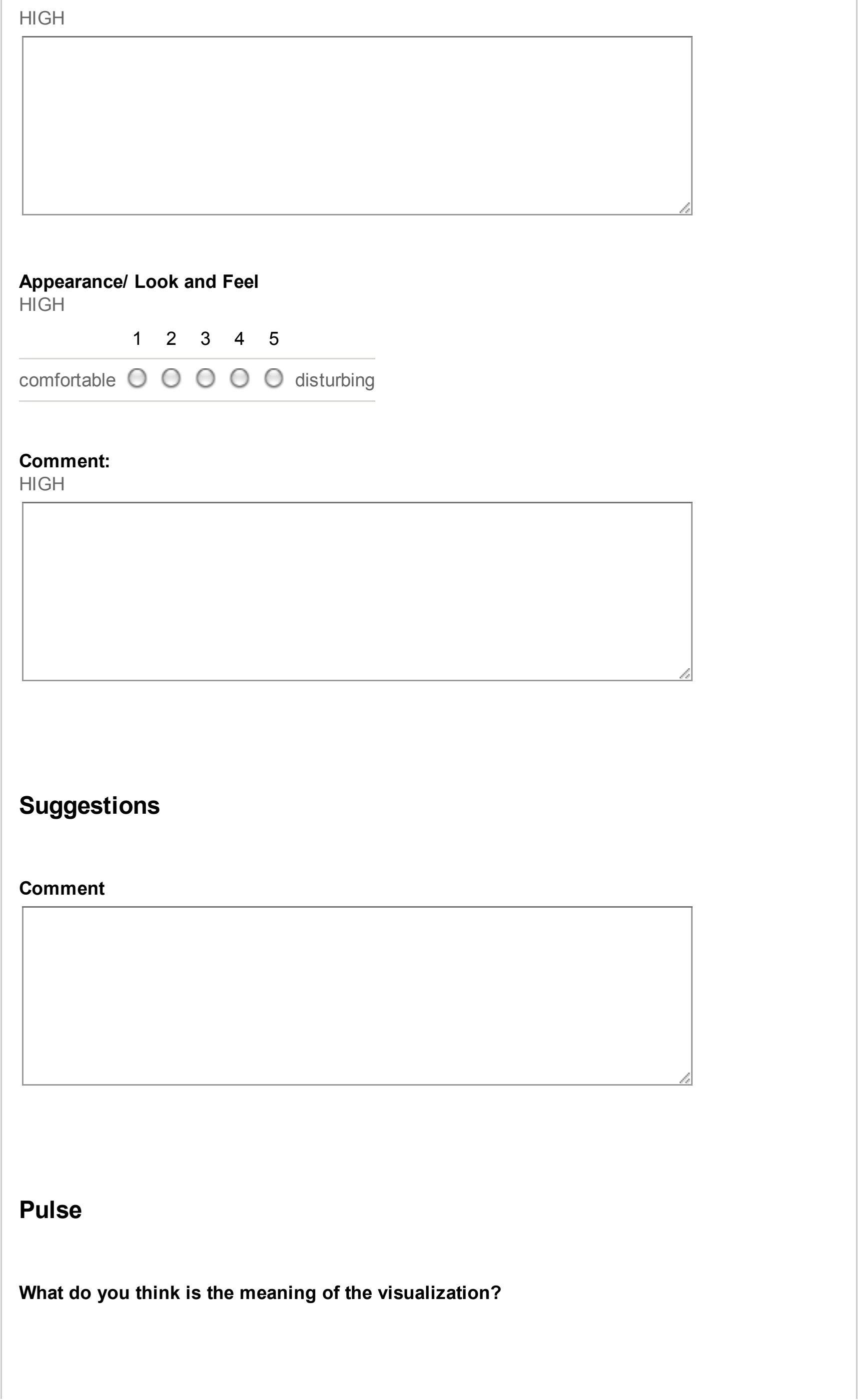
HIGH: test four devices

How much fits the visualization the appliance?
HIGH

	1	2	3	4	5	
very little	○	○	○	○	○	very much

Comment:

Figure F.5: User Study Part 5: Hardware Prototype



HIGH

Appearance/ Look and Feel
HIGH

	1	2	3	4	5	
comfortable	○	○	○	○	○	disturbing

Comment:
HIGH

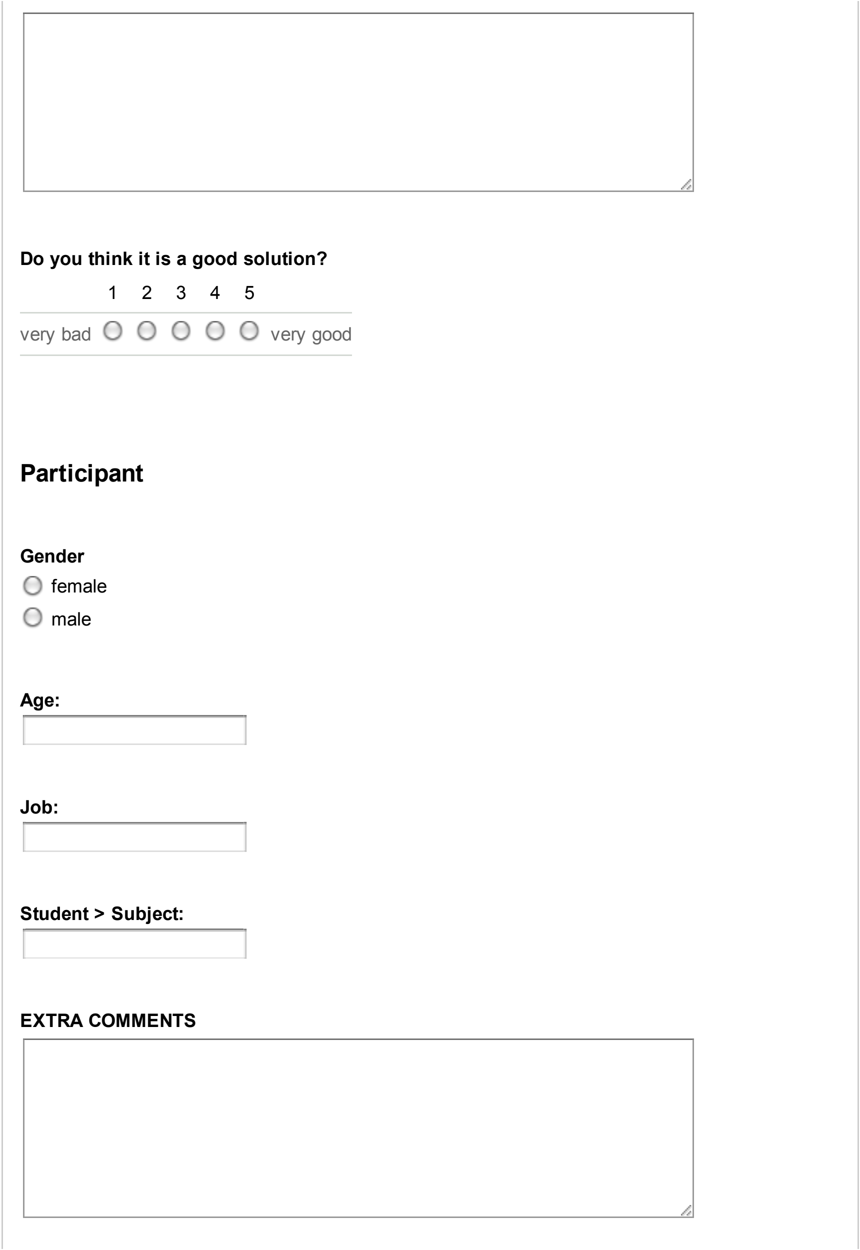
Suggestions

Comment

Pulse

What do you think is the meaning of the visualization?

Figure F.6: User Study Part 6: Hardware Prototype



Do you think it is a good solution?

	1	2	3	4	5	
very bad	○	○	○	○	○	very good

Participant

Gender

○ female

○ male

Age:

Job:

Student > Subject:

EXTRA COMMENTS

Figure F.7: User Study Part 7: Hardware Prototype

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