Bauhaus-Universität Weimar
Faculty of Media
Degree Programme Human-Computer Interaction

Bauhaus-
Universität
Weimar

Designing an Interface for Connecting a Web of Things

Master's Thesis documentation

Mark Eisenberg
b. 29.12.1992 in Limerick, Ireland

Matriculation number: 116453

1. First Referee: Prof. Dr. Eva Hornecker

2. Second Referee: Junior-Prof. Dr. Florian Echtler

Submission Date:

Acknowledgements

I would like to thank my supervisors Prof. Dr. Eva Hornecker and Junior-Prof. Dr. Florian Echtler, who offered great guidance and assistance in the conception and development of the Master's thesis.

I am very grateful to my close friends and colleagues in the Human-Computer Interaction and Computer Science and Media Masters courses. They have offered fantastic support and lasting memories throughout my two years in this Master's course.

I would like to thank my wonderful parents and sister, who lovingly supported and helped me along this tremendous educational journey.

Declaration

I, Mark Eisenberg, declare that this thesis is my own work and that I have cited and acknowledged source material. Quotes and definitions have been cited and referenced in this report to the best of my knowledge. I understand that plagiarism is not tolerated for academic writing according to the academic regulations set by the Bauhaus-Universität Weimar.

Signed:

Date:

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List of Abbreviations

API – Application Programming Interface

CSS – Cascading Style Sheets

GUI – Graphical User Interface

HCI – Human-Computer Interaction

HTML – Hypertext Markup Language

IDE – Integrated Development Environment

IoT – Internet of Things

IR – Infrared

JS – Javascript

LED – Light Emitting Diode

MAC – Media Access Control

MQTT – Message Queue Telemetry Transport

NFC – Near-Field Communication

OSC – Open Sound Control

QR – Quick Response Code

RF – Radio Frequency

SVG – Scalable Vector Graphics

TUI – Tangible User Interface

WoT – Web of Things

1. Project Summary

This project involves the creation of an interactive Internet of Things (IoT) interface that allows users to visually connect objects to one another using NFC and touch. The interface is projected into the physical space and mapped to the object's positions. Through these visual connections, users can change the state of multiple objects using either a physical or digital switch of only one connected object. The purpose of the connected objects is to give users a direct understanding of what objects are connected and their current state. By having the objects connected across a space, the system's purpose is to also allow a more convenient approach to switching the states of multiple appliances.

This 'web of things' system is constructed from a combination of web development programming languages like HTML, CSS, JavaScript and NodeJS, as well as pre-existing interactive software packages, libraries and IDEs. Hardware components include the Microsoft Kinect, Arduino an Android smartphone with NFC capabilities, four appliances, four radio frequency sockets and four Amazon Dash buttons. All of these technologies come together to create a so-called 'interactive display' where the user can visually connect objects to each other using NFC and a touch-wall. In addition to the development of the interface, the project also contains a study of users and their interactions with the system.

Household objects often have an interaction method built in that their owners already understand. The intention of this system was to make the already built-in functionality of objects congruent with the new interaction methods. Many modern IoT systems make use of mobile or desktop interfaces to give wireless functionality to household appliances. These systems sometimes allow for logical if-then statements to be constructed, but these are often abstractly formed and must be remembered by the users. Therefore, this project seeks to examine how an embedded logic interface can impact a user's interaction with their household appliances.

The following report contains research that helped develop my understanding of existing IoT interfaces and related concepts, technical information relating to IoT development, as well as the theories behind interaction design. This report will detail the processes used to create the Web of Things system. Concept development and design choices are outlined within the implementation stages of each respective product section.

2. Introduction

The following section shortly describes the project as a whole, the reason for its initiation and its desired outcomes based on requirements, respectively.

2.1 Project Overview

The main purpose of this project was to develop a system that allows users to establish visual connections between devices and control the objects through these connections. The design and development of the interface was preceded with a low-fidelity prototyping session with users. Here the users were able to both explore their own Internet of Things system, as well as testing the envisioned system using low-fidelity materials. The feedback was then taken into consideration and the final prototype system constructed. During the development, various design and technical challenges had to be taken into consideration when building a low-cost IoT system. A user study was then conducted on the final interactive system. From the study a manifest of topics was collected, which outlined the most frequent feedback. This data was then examined and compared with the low-fidelity feedback and existing literature.

The final interface, entitled “HomeNodes” in this project, can be controlled using touch interaction, an NFC-enabled smartphone and four Amazon Dash buttons. A projector is used to project the interface onto the surface near the physical objects. Using this method, the properties of the objects and the established connections are mapped into the room and near the objects. The interactive display makes use of the UbiDisplays [16] program to display the interfaces and embed the touch interaction. The left side of the interface allows the user to switch between and connect ‘external’ objects that are not in the room using touch controls facilitated by the Microsoft Kinect [39]. The Kinect camera tracks the user’s hand movements in relation to the projected wall display and creates touch events when the wall is touched. The right side of the interface shows the objects ‘state nodes’, the connections between these nodes and is not touch-enabled. The connections are established by touching two devices successively, on the left display using direct touch and on the right by tapping the smartphone on the objects. Once the connection is made, the user can then do multiple things. The first is using the physical switch to turn on one device, which then turns on the connected devices. The second function is the ability to delete a connection by doing a ‘reverse’ connection and pressing the bin icon on the touch interface. The user can of course then decide to connect more than two objects together to create an interconnected web of things. This, in the end, is up to the discretion of the user and also how they would prefer (or expect) the logic to work.

The connected home overview

The study room itself, where the HomeNodes system is set up, is organized much the same way as a regular living room. The four household objects used for this project included two small loudspeaker systems (acting as a speaker and radio respectively), a PC monitor and a desk lamp. Due to the different extra hardware and software technologies present in the system, the room was unlikely to become a truly ubiquitous connected home scenario where the technology is barely visible. However, the purpose of the study was not to make the system truly ubiquitous, but rather to simply take advantage of the living room setup that was available. This made sense while testing a home IoT system, in contrast to a fully controlled lab scenario.

Reasoning for embedded interactive display approach

Smartphones have existed for more than a decade and has changed personal productivity and global connectivity [22]. Modern smartphones are incredibly versatile, and are more frequently being used for purposes initially unintended. This now includes the ability to connect, either via a computer or smartphone, to one's home automation system or simply a WiFi enabled lightbulb. However, this has then modifies the 'traditional' use case between a user and their home appliance. Before an appliance could be turned on and off and later some settings changed. Now, a home owner can potentially turn off their lamp via a smartphone or change the lamp's settings manually and have the power usage data be captured and sent to their desktop spreadsheet [12]. The latter is of course hugely beneficial and proactive for a house's energy monitoring and in many cases is simply automated via timers, thresholds and notifications. On the other hand, there may be cases where people don't want to try and remember which lightbulb out of 30 [18] they had connected and if their toaster was using inefficient power. This project aims to facilitate the scenario where people just want to make life a little easier and not individually and manually turn on their lights when they wake up or return from work. Pre-configuration is of course required, but the results should be immediately obvious to the person controlling their home appliances. The development of the HomeNodes interface can be described as 'Interaction Design'. Sharp, Rogers and Preece give a short definition at the beginning of their book "Interaction Design: Beyond Human-Computer Interaction", describing it as a way of "developing interactive products that are easy, effective, and pleasurable to use – from the users' perspective." [34] This description, along with the related research in this paper, guided the Interaction Design methodology in the creation of the HomeNodes system.

One could also view the end system as a form of TUI (Tangible User Interface). In a paper from 1997 by Ishii and Ulmer "*Tangible Bits: Seamless Interfaces between People, Bits and Atoms*" [19], they describe, at their time of writing, that "interactions with...GUIs are separated from the ordinary physical environment within which we live and interact." While multiple strides have been made since then in product design to bring the physical back into computing, there is still a preference and preconceived efficiency of GUIs on screens. The goal of the envisioned system is to return as close as possible to the traditional use case of a home appliance (i.e. physically interacting with visible devices), without alienating the user with the added features.

Technologies and programming languages used for system development

The front-end of the web application was created using HTML, CSS and some Javascript. Some of the Javascript functionality was included directly into the HTML within script tags, but the main logic was included in a single Javascript file. The back end combined multiple existing software packages plus small program sketches written in Processing IDE acting as communication intermediaries. A Breakout server was used to establish a communication channel from the browser window to an Arduino Deumenilove pair (Fig. 1). A diagram can be found in the Appendix (Appendix A.6).

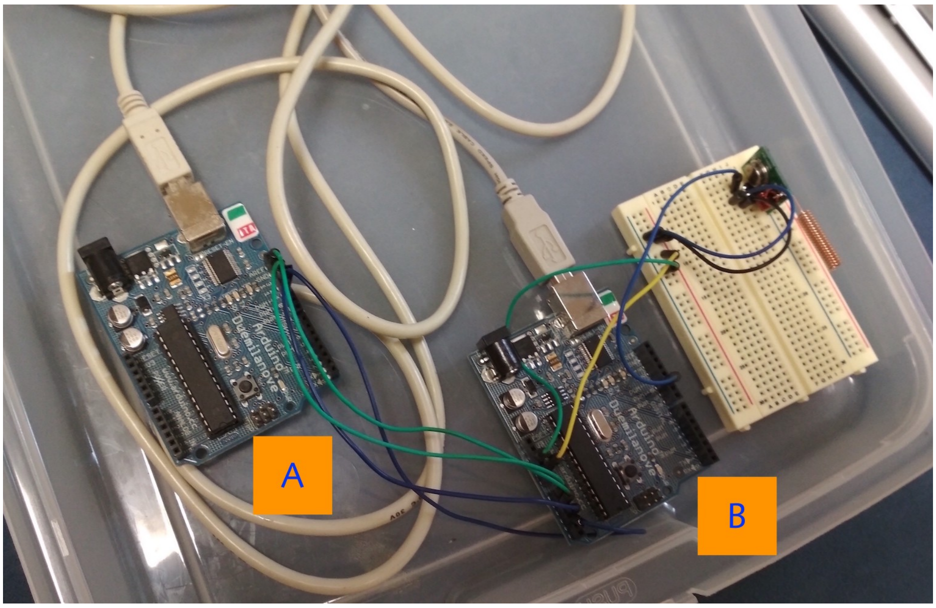


Fig. 1 – Arduino A: Breakout server. Arduino B: Logic control for RF.

Between the two Arduinos, one contained the code for receiving and sending signals from the Breakout server and the other for decoding these signals and subsequently activating one or more radio frequency power sockets (Fig. 2).

Fig. 2 – Four 433Mhz Radio Frequency Sockets

A Microsoft Kinect and the UbiDisplays [16] program was used to create a touch-enabled projection surface. Button press communication between browser windows was facilitated using a communication library called BNC Connector [47]. This small communication channel allowed for HTML button presses to be converted to serial messages for the Arduinos. The Spacebrew [58] toolkit was used as a versatile way of sending messages between multiple browser windows, as well as Processing sketches (programs written with Processing). To send a selection signal from a household appliance to the system NFC tags were attached to the objects. An Android application called Sensors2OSC [58] was used to emit the ID of the selected object via OSC messaging protocol. A Processing sketch was then used to receive this OSC data, shortly parse it and subsequently hand it via Spacebrew to the system.

2.2 Motivation

The idea for this project was inspired by the Reality Editor by Heun et al. [18] built within the Fluid Interfaces group of the MIT Media Labs. Their front-end also make use of nodes and lines to connect objects and uses augmented reality to interact with QR-code tagged objects. However, they have developed a quite sophisticated system where it is possible to connect multiple functions of one object to multiple functions of another object, essentially “connecting the numbers associated with a given object”. Thus, their system allows them to send intermediate values between 0.0 and 1.0, which makes for much more granulated and interesting shared functionality. Another positive aspect with using Reality Editor and its Augmented Reality to connect objects, is that it is possible to still follow the connections between widely spaced objects, by either tracing the connection or stepping back to get the full scene in perspective.

The goal of this project was not to emulate the work from Heun et al., but rather to extend the system out from the smartphone and into the world via projection and physical interaction. Modern society is familiar with the mobile interaction methods like tapping, sliding and dragging, so smartphone interaction makes sense in the context of connecting objects. This project seeks to explore the interaction space outside of the screen, other perspectives on how we can visually connect objects and the reactions that it can elicit.

The Internet of Things is still an evolving field and this project aims to enlighten the parts that are still unexplored. Porcenaluk writes in his article that “if connecting that coffee pot to the internet doesn’t enhance the experience, then don’t do it” [31]. There is an unusual thought process when one is presented with the ability to connect one device to another without some sort of adapter. One must question the need and result from doing such an action. The Internet of Things is not exempt from the growing trend of automation and machine learning. Computers could eventually have the ability to connect devices according to pre-processed preferences, without the user having to lift a finger. Nevertheless, like many other aspects of computing, design input from humans is implored, regardless of how advanced the technology is [32]. Having studied the existing literature and after consultation with some HCI professionals and academics, it is clear that the Internet of Things field has still many aspects that need to be explored.

Web technologies were chosen for this project because of having previous personal experience with web development and design. Additionally, the UbiDisplays program allowed the use of web content for the interactive display. As such, UbiDisplays was chosen as it is quite intuitive and required much less internal modification. IoT systems already interface with standard HTML5, CSS3 and Javascript, with additional NodeJS and Javascript libraries making the interface streamlined and automated.

2.3 Project Requirements

The aim of the project was to create an interactive interface that allowed for two or more household objects to be connected. The application had the following 'functional requirements':

- Visually connect two or more object nodes together.
- Visually delete the connection between two objects.
- Physically interact with the objects to connect them or change their state.

The 'non-functional requirements' of the system are:

- Create a usable user interface for the home environment.
- Create a user interface that gives appropriate feedback and doesn't overly distract users from their home appliances.
- Give the users some freedom to explore different combinations

In addition to the above requirements, another desired outcome was to explore and document the methods of connecting an Internet of Things system using web technologies. The knowledge and techniques gained could still be applied to daily life and potentially in commercial IoT systems.

The requirements outlines above represented milestones in the project, with the alternative milestones being present in the project plan (see Appendix A.7) created at the beginning of the project.

3. Research

3.1 General Introduction

Over the course of my Master's thesis I have developed my skills in Web Development, Product Design, Interaction Design, User Experience Design and partial IoT Theory.

The primary inspiration came from Reality Editor, but through literature research I was also able to get a wider sense of the current state of the Internet of Things field. It was clear from the outset of the project that research into other IoT interfaces was needed, as it was likely the concept could have been earlier implemented. It was found that while many research papers drew certain parallels and gave related concepts, the exact system of using projection to visually connect household appliances was not quite yet explored.

3.2 Inspiration for interaction

As described earlier the primary inspiration for the interaction came from the Reality Editor program [18]. When one uses the Reality Editor application for iOS devices, they can use the device's camera to scan the environment for specially-printed QR codes or patterns attached to objects. Objects such as a smart lightbulb or Arduino can be visually connected to each other by drawing a line between circular nodes on the touchscreen. Features also include the ability to delete lines by using a cutting gestures, moving nodes by dragging them as well as a very in-depth logic system that allows intelligent interconnectivity between previously disconnected objects. Users can also take a picture of the scene with the QR tags and then modify the connectivity later on.

As such, only the line creating/drawing functionality and deletion functionality was extrapolated from the work by Heun et al.

The authors describe the benefit of using augmented objects rather than "an abstracted representation of such a system". Augmenting the objects allows for the designer to "generate a direct mapping".

The work done in Reality Editor expanded the thought process of singular binary relationships between objects into a multifunctional interaction between internal parts. The HomeNodes project is more focused on discovering the pros and cons of making a binary interaction between objects work as an embedded projection interaction. Therefore, the logic system was constrained to a base mult-device switching interaction due to the additional complexity and variety of electronic construction and programming. Purchasing multiple commercial smart devices, including the construction of custom 'home appliances' or electronics with smart features built in, were considered as nonessential costs.

3.3 Existing IoT interfaces

The IoT interfaces and literature described in this section deal with the controlling of objects using unconventional methods.

3.3.1 UbiDisplays: Toolkit Support for Interactive Projected Displays

This open source toolkit, created and documented by Hardy and Alexander [16], was discovered early on in development, and its simple configuration made it the top choice as the IoT touch wall interface for HomeNodes. As of writing, the toolkit has not been updated by the developer since 2013 meaning that bugs and crashes still occur while using the program. These are described further in Section 5.4.1.

The authors reflect on previous systems used to setup touchable surfaces and comment that there wasn't a simplified configurable system which properly supported "application driven research". The target demographic for the authors were people who could make use of the "transferable skills" of web development standards.

The Kinect camera must be placed close to the projected surface. This is due to the lack of points in the 'point cloud' required by the Kinect at larger distances. When the UbiDisplays program is launched, the user must select their surface (the projected surface) and the Kinect camera. A screen appears with calibration markers which can be repositioned into the camera's frustum. One must click on the calibration points on the video feed to calibrate. The program is then able to estimate, based on marker size and the depth information, how close the surface is to the camera i.e. an "homography matrix". Screen orientation and dimensions data are given to the back end. Thus, the camera can be placed at an angle towards the surface without major issues. The authors recommend using large User Interface (UI) elements to prevent error in recognition.

During their evaluation of the toolkit, some designers and testers made note that it was important to take "careful consideration of the colours (and other design choices) as the material and texture of the [surface] greatly affected visibility." This highlighted an interesting aspect on the design of the interface. When projecting, the colour black does not interfere with the projected scene. However as soon as colour is introduced, one must think about what can be visualized and perceived correctly.

The video demonstrations given by the UbiDisplays team also show the use of a projected touch surface as a light switch [21]. This provided a confirmation of its practical abilities as an IoT interaction method.

A positive aspect of the UbiDisplays program is the ability to save the calibration settings, which means that, provided one does not move the Kinect camera, the touch surface can be setup in a matter of seconds. On the other hand, the authors encourage designers to "experiment with such designs, taking advantage of physical shapes and embodied context." As discovered in the "Exploration of further interactive technologies" section, this is not so straightforward when trying to create a touchable display near objects which distort the calibration.

3.3.2 WorldKit: rapid and easy creation of ad-hoc interactive applications on everyday surfaces

The WorldKit project by Xiao et al. [43] was the closest to the desired output for the Master's thesis project next to UbiDisplays. While the WorldKit software was not available for testing, much of the same hardware is used within HomeNodes, namely a projector and a mounted Kinect camera. This was an interesting implementation because it allowed users to draw an interface on a surface. The newly created interfaces can then act as controller for the environment, such as a volume adjuster or light dimmer. They note in the paper that it is still possible for the user to occlude the projection or camera, thus losing the interaction immediately. This fact was noted for this Master's project and influenced the design choice for the final connected interface [see Section 5.4.3]. The shadow of the user's hand is given by the authors as a type of feedback, allowing the user to know how far their hands were away from the wall. Audio and voice interaction is also recommended from the research, as audio and particularly voice may help increase the accuracy of exact presses or gestures towards devices. This however is an extra task for the user, requiring the user to learn and remember what could be possible as a voice input for a single UI element. The authors also list a number of other projects which use image analysis (among other methods) to differentiate what is in front of the camera and thus giving the possibility of modifying the interface or the information displayed. This is in contrast to this Master's thesis, which has a hard-coded interface for interaction.

3.3.3 A Survey of User Interaction for Spontaneous Device Association

In order to properly classify what category HomeNodes falls under, one can look to a paper by Chong et al. [8] which surveys a large sample of device connection methods and technologies. The authors refer to connecting two objects together without a direct cable connection as “spontaneous device association”. In the research conducted by Chong et al., security was beforehand considered the most vital research topic in the connected devices field. Their own work was more interested in finding the differences in user interaction. They describe how a user often has to try out the interaction or read a manual before building their “conceptual model”. It would be much more beneficial to have the conceptual model built much quicker through self-evidence. A multiple device interoperability is a key aspect of ubiquitous computing, where the system can be changed dynamically [8][23]. One could make each device visible directly, or indirectly through separate channels (as is with HomeNodes). “Pairing” is the most common term used when referring to the connection between two or more devices. The objects or devices become a pair, sharing a communication channel that is most often initially locked to outside devices. With Bluetooth, for example, this connection is visualized often through the use of the Bluetooth icon on the status bar of the device, or as an LED that becomes a certain colour (eg. blue). The icon may also include the name of the connected device, but outside of this there is no active way of looking at two devices and discerning if they are paired.

The authors list four association techniques: Guidance, Input, Enrolment and Matching. These are a collection of steps in the path a user takes to connect or associate objects or devices.

1. Guidance refers to the initial physical state of the devices in relation to each other and what affordances they may have in relation to each other. The functions in using two devices can be implied or explicit (eg. pointing the infrared side of the remote to the television, male and female sockets).

2. Input is the act of conveying information to the device to change its properties. This is essential for any direct or indirectly connected objects.

3. Enrolment involves giving the device an identification and how this identification is established (eg. through passcode or other security measure).

4. Matching gives the opportunity for the user to confirm or deny the established connection based on the [synchronous] feedback.

The paper is quite extensive and gives multiple examples of varying connection methods. Included is a system known as “GroupTap” by Chong et al. [8]. This involved using attached NFC tags to pair two Bluetooth-enables devices. Here they note the extra physical requirement to connect two devices. Attaching physical tokens, such as in “tranSticks” is listed as another way to visually identify a dual wireless connection between devices. This of course, requires the user to spot the assigned visual indicator, be it a colour or symbol, from their collection of devices. Mayrhofer et al. [8] created a system in 2007 where they coined the term “Spatial References” for use in the ‘connected devices’ field. In this system the devices are aware of their positions relative to one another and can modify the connected interface on the visible screens. By pointing to the target devices, association was made in a more straightforward manner.

The authors give also a short overview of the evaluation methods possible for device association. These include various quantitative and qualitative method, including comparative studies between two technologies, but also outlines “User-Defined Action Studies” whereby a user can develop their own logic for connecting devices and quickly prototype their methods. The authors completed one of these studies in their previous research using plastic representations of wireless pairable devices. The participants in the study were influenced by their pre-conceived notions of how the technology traditionally works, as well as new well-known techniques (eg. touch-swiping, long-press).

For recommendations, the authors suggest taking studies out of a strictly controlled lab environment and ‘into the wild’.

3.3.4 Toward Interoperability in a Web of Things

This paper by Blackstock and Lea [7] explores and describes some current IoT interfaces and outline some recommendations how the new and diverse range of technologies might converge into a global standard.

Using the web not only as a way of sharing information, but as a standardized language that allows for intercommunication between local machine and wider cloud based hubs. One point that they make clear in the paper is that by making multiple IoT technologies follow a certain rule book, there may be a stifled expansion of new ideas and would thus lead to an alienation within the technology community. Because the Internet is already widely accepted and utilized as a way of ‘unifying’ people, it can also potentially do the same with smart objects. Objects and their individual parts can be identified and indexed like computer files and documents where “sensors and actuators can be represented as resources, and information about these things can be exchanged”. A trend today is to used “cloud-hosted platforms” to bring connectable devices online. Like other technology developments it allows for a potentially quicker way for information and devices to communicate cross-platform, especially if the platform has a browser. Older methods require knowledge of setting up servers and gateways either in the client or the device. The cloud platforms, or other platforms that can exist offline and online, are able to automate many of those processes. A problem that the authors have with current WoT implementations is that they are so-called “islands of control”, which are largely separated from the outside world. While having these islands separated and controlled individually may be beneficial for security reasons, a standardized system could alleviate some worries of consumers who are unsure of the system in which they are investing. Consumers should be in control of as much of their own data as possible, but not be constricted and confused by the unpredictability of non-standard IoT islands.

The authors then describe the different Web of Things (WoT) hubs that can exist. The first are ‘Web-enabled IoT products’, which are consumer products that people can buy to control using their home network and smartphone. The second ‘Web-centric IoT platforms’ can be found in industrial and company settings where ‘proprietary APIs’ are used over the web to facilitate access to products, machines and other systems. The final example, directly called ‘WoT Hubs’, are toolkits used to aggregate smart objects and sensors. The feeds from the sensors can then be analyzed and used to perform a function in the system. For sharing sensor feeds, the Open Geospatial Consortium (OGC) has created a framework, hoping to introduce a sort of standard. In a similar vein to feeds, 'mashup tools' have been used to concatenate multiple inputs and outputs such that one can create unconventional ways to operate smart objects. An example is IFTTT (If This Then That) where recipes can be written to trigger an action on receiving communication from a web service. "IoBroker" [53] is another IoT interface compatible with Homematic.

In order to create a standard, the authors suggest collecting what would be considered the important details of the smart objects – their representation, 'findability' and accessibility. Information should be made clear as to what are aspects the 'things' in the Internet of Things should be agreed upon, before any definitive individual or company recommendation can be made. This includes the thing's: definition, interaction, identification, description, location, organization, security and history. The value of the hub systems increase the more people use and accept them. The IEEE also set technical and protocol standards for the Internet of Things, although the authors of this paper mention this is mainly within single network systems and not 'hub-to-hub or hub-to-application interoperability'. They warn that using standards can help with cost-savings and feature richness, but stifle innovation. Without the standardization, the communication needs to be modified and adapted so that information is equal on both ends of the pipeline.

They list four levels to help achieve this interoperability: a *WoT Core* which make use of web services, developers and mashup tools. This level is the basic level and requires some 'heavy lifting' and system understanding from the developers to operate sufficiently. The *WoT Model* refers to the high level method of cataloging the items and their details. Within the *WoT Hub* level lies the visualization and representation eg. the links that might be a URL or code. The back end contains a secure method of sending the data and automation, such that developer involvement is minimal or non-existent. Finally, the *WoT Profiles* are the semantics and taxonomy of objects that are consistent across hubs.

The ideology described in this paper was brought on by the authors involvement in the creation of a IoT system for use within road networks and used their system called 'WoTKit'. Using this system they could analyze the data from the road (conditions, flooding etc.) and control signals and other equipment.

In a world full of choice and clashing opinions, having certain standards within IoT is more beneficial in the long run. Standards bring the user towards a more open and choice driven experience within their home. They can then go to a certain brand and know that it is, or at least some part of it is, compatible with their old model. As Donald Norman states "the User Experience encompasses all aspects of the end-user's interaction with the company, its services, and its products" [60]. This means that one can be very innovative and change the paradigm of IoT interaction, but one should always make sure that the product's key features function without issue and provide a good base user experience.

3.3.5 Other notable IoT interfaces

PICOntrol: Using a Handheld Projector for Direct Control of Physical Devices Through Visible Light

Developed by Schmidt et al. [37], this project involved the development of a device controller that was operated via visible light. The controller was composed of a handheld pico projector with push buttons. Sensors were then placed on the controllable objects. The projector would then send custom encoded signals to the object at which it was pointing. These signals could then interact with the device or appliance in different ways. Thus, a user could essentially point their visual 'user-interface' onto any object and control it. In the implementation shown in the paper, devices were controlled within a space of the projection like a remote control. An expansion of this project would be very interesting for connecting objects. With reliable tracking of the attached object sensors, one could display a real time 'hidden' interface where one device could be clicked and then connected to another device using a second click. The projector could then essentially act as an Ultraviolet lamp that illuminates connections between devices.

Another similar technology was made by Funk et al. [13] where the projector was mounted on a helmet, allowing for hands-free movement.

Snap-To-It: A User-Inspired Platform for Opportunistic Device Interactions

This paper by de Freitas et al. [10] described the development and uses of a smartphone interface to control devices from a distance. Photographs of devices are analyzed using the SIFT (Scale Invariant Feature Transform) algorithm in combination with location and orientation of the smartphone. This allows for the device to be correctly identified and then the ability to give arbitrary user interfaces or actions to them on a smartphone.

Deus EM Machina: On-Touch Contextual Functionality for Smart IoT Appliances

Device proximity activation using tools such as smartphones gives users a unique opportunity to physically interact with an object than the modern popular digital abstractions. The paper 'Deus EM Machina' by Xiao et al. [44] makes use of a smartphone augmented with an electromagnetic reader to 'sense' the object that was touched. One can't expect all home appliances to have a built-in chip to communicate with the handheld device. Therefore the authors developed this to identify the 'un-instrumented' home appliance via its electromagnetic signal. its accuracy proved to be quite high with different objects in a regular home environment. The problems they encountered were with same brand devices and electromagnetic interference.

3.4 Evaluating IoT interfaces

In order to get a better sense of the usability of the HomeNodes system and whether it actually influences the convenience factor of home appliances some user evaluation must be done. Therefore, research was done into evaluation methods used for interactive multimedia systems. Typical interaction design related exploratory evaluation methods were used in these papers, making them suitable for the HomeNodes project.

3.4.1 Designing and Evaluating Multimodal Interaction for Mobile Contexts

The paper "Designing and Evaluating Multimodal Interaction for Mobile Contexts" by Lemmelä et al. [25] described the construction of a mobile interface that changes its modality based on the user's context. The authors remark on the 'social acceptance' of their proposed interface, essentially asking the question: is the technology needed? They used a pre-made evaluation technique useful for both laboratory and field study settings. The researchers first did contextual observations, analysis and subsequent storyboarding across contexts before interviewing participants and conducting participatory design sessions. From here they then built their prototype and evaluated using interviews, video and observations. Their developed software was a messaging application that included multiple input modalities such as speech, touch and gestures. Their results showed that speech was more valued while in a car context and that 2D touch and 3D gestures were interchangeably used while in a walking context. The authors also note the lack of comprehensive multi-modal toolkits available for seamless switching in different contexts. They surmise that this absence leads to interaction designers combining multiple indirectly connected systems and toolkits.

In terms of its similarities to HomeNodes, the multiple modalities developed in this paper resemble the two modalities that occur in the user's IoT context. However, the interfaces that exist in the current version HomeNodes do not change dynamically to the context of the user, as it is hard-coded.

For the evaluation methods, the author's techniques fit quite adequately to the explorative nature in designing the HomeNodes system. The main difference was in the context observation. This was not seen as a required evaluation method as the context of use was unchanging in the HomeNodes scenario. In contrast to the desired outcomes of the researchers, the participatory design approach for HomeNodes seeks to explore how a common user's understanding of typical graphical user interfaces might influence their 'novel' interaction solution, be they an experienced designer or a normal home owner.

3.4.2 Design and Evaluation of a Dynamic-interactive Art System: A Mixed Methods Approach

This paper by Andrade et al. [2] made use of both qualitative and quantitative methods to evaluate an interactive art installation. While the system's purpose was for mainly expression and artistic endeavors, it still includes suitable evaluation methods for an interactive system like HomeNodes. Their system used the Microsoft Kinect to control musical playback with maximum of two participants. Their evaluation method included the use of the PANAS questionnaire to quantitatively measure the user experience and emotional impact on the user. For getting a sense directly from the mouths of the users, semi-structured interviews were run. Themes were subsequently drawn from the interviews during their two iterations. This included the amount of 'control' the user had over the system, their 'feelings', the 'core purpose' and 'social interactions'. From these themes alone, they were able to make design decisions about the system, including changing recognition patterns and removing the frustrating aspects found in their first version. From their interviews it was possible to see the gap in requirements between the artist and the developers. The artist sought after something unpredictable, whereas the interviews and questionnaires pushed the developers to make something more controllable. While this difference existed it was found that the mixed method approach, in the researcher's terms, made their findings richer.

3.5 Room Interaction Design and Spatially Distributed Interfaces

Using devices in a large space could potentially impact the usability and form of interaction the user can achieve. These papers explore cross-room and cross-surface interaction and the construction and exploration of some interaction methods. HomeNodes does not actually operate across rooms or surfaces in its current implementation, but this research serves as examples of expanded interactive systems that span different nearby locations.

3.5.1 The Cube: A Very Large-scale Interactive Engagement Space

"The Cube" is a multi-surface and multi-room interactive installation created during 2012/2013 within the Science and Engineering Centre in Queensland, Australia [33]. It is a multi-display installation that allows researchers and companies to showcase their material and is especially known for its interesting visualizations that are centered around educational content and unique interactions. While mostly dealing with touch-based interactions, some experimentation has been done with alternative interactions such as skeleton tracking and gestures. The Cube originally was planned to be on two floors with rear-projected multi-touch setup. They found this design had a number of issues, including not making efficient use of the space and that the projection technology had a limited resolution. To make most of the space and attract crowds they included a mixture of technologies – multi-touch displays towards the bottom of the surfaces and projections above the screens. These surfaces were often perpendicular to each other, meaning that the displayed content often had to be synced across multiple displays. Altogether there are six zones containing the same or similar display technology, making a set of quite large interaction spaces. While mostly a technological accomplishment, the Cube is known for its flexibility in the sort of interactions and content that can be brought to multiple large screens. Designers have to think about displaying content across multiple large surfaces and make use of the available screens to allow for sensible touch interactions and GUIs. The authors explain some issues and requirements after testing with some users, such as including a "small circle around each registered finger" so that users could understand their interaction better and that by attempting an interaction across two screens (the two touch screens could be considered one display), then they would attempt "to pinch zoom with two hands on adjacent screens (which the system would interpret as separate users)." The initial software showcased on the wall varied between educational, video, unique interactions, games and multi-user sharing.

3.5.2 Using Overlays to Support Collaborative Interaction with Display Walls

The paper by Satyanarayan et al. describes the beginnings in development of a digital 'Overlay' which supports multiple users on vertical display walls [36]. The authors in this paper were interested in finding out more about the implications of interactions within more ubiquitous displays that come at different resolutions. The authors note that large vertical displays are more difficult for users to use in comparison to tabletop displays with its "fluid interaction" affordance. Using a low-resolution input device on a high-resolution display also does not benefit the user as they found it "difficult for users to accomplish fine-grained manipulation of small objects on the large display" and also distant objects are hard to reach. Accelerated mouse movement can be used in this case, but then the "cursor tracking" becomes difficult.

Their interface aimed to help "to focus users' attention on a small subsection of the larger display, and aid allocation of display space across users." They trialled three different input method: multitouch surfaces, touch screens and digital pen and paper. Their results from their tests showed that the interactions across devices with the Overlay were quite natural, provided the aspect ratio fit the screens. The input devices allowed them to 'attend' to the larger wall, but that "dragging or...scaling...still felt tedious."

This paper draws parallels to HomeNodes in its testing and combination of multiple modalities. It shows that each intricate programmed aspect of the system should give the user a sense of consistent control over the interface. HomeNodes also gives users the option to approach the system in a different way, connecting different objects and activating them physically or virtually.

3.5.3 Towards More Natural Digital Content Manipulation via User Freehand Gestural Interaction in a Living Room

This paper from Lee et al. [24] outlines the use of a slightly modified Wizard-of-Oz approach, in which the authors analyzed in-air gestures. They use mainly video analysis to collect information about the gestures created by only non-expert users. Their motivation for the living-room environment was that a lot of research at that point was focused around standing gestures and not gesture interaction in a relaxed approach.

The authors argue that due to the physical effort required for 'purely' natural gesture interaction, other techniques are just as valid. This can include short waving motions or movements that can be transformed to larger outputs. Their research included a study of group gesture construction which found that users preferred gestures from non-expert users. By conducting methods like the Wizard-of-Oz approach, guidelines and recommendations can be made for designers and developers, without the heavy time and effort of building and testing a fully functioning system from scratch. Their modification of the Wizard-of-Oz approach allows the user to revise their proposed gesture (normally not done in Wizard-of-Oz) and potentially gain a different sort of feedback. The authors were interesting in finding out the changes in behaviour if the users were not happy with how they mentally envisioned it. During the tasks assigned by the researchers a 'performer' would complete the action and a 'recognizer' would complete the action with a Wacom tablet. From negative feedback in their pilot study they then decided to allow the users to create their own commands.

Their results found that the amount and way that the users gestured varied over time (growing smaller) and changed slightly depending what the visual representation showed on the screen. They implore designers to include recognition of both discrete and larger gestures in various sitting poses. With their approach using 'performers' and 'recognizers' the authors believe they have evaluated gestures with the required aspects of user's *desired*, *expected* and *sensed* actions.

In order to give the participants of HomeNodes an early impression of the proposed system during the low-fidelity prototyping sessions, a remote was used to control the RF adapters. This then acted as a form of the Wizard-of-Oz method for this portion of the study. These aspects of relaxed gesture interaction could be applicable to the control of a home automation system in a living room.

3.5.4 Other notable literature

Combining Multiple Depth Cameras and Projectors for Interactions on, Above and Between Surfaces

Wilsen and Benko [42] at Microsoft Research developed a system that allowed users to stand between a vertical screen and tabletop display and transfer information by touching both surfaces simultaneously or transfer as if they were holding it in their hands. They used depth cameras to capture the 3D point information and projectors to map the visuals on to the spaces and the user's body. Whilst experiencing latency issues and occlusion issues, the researchers found that the users of the system were able to sufficiently operate the system. Their participants even managed to transfer data by holding each other's hands, creating a transfer link.

Making Technology Homey: Finding Sources of Satisfaction and Meaning in Home Automation

Automation systems have different origins. Systems that might have been used in industry make their way to homes in the form of consumer products. Takayama et al. [40] surveyed different home automation systems to verify if people really did find them usable and if they were meaningful to the users. Their results highlighted that the most popular applications assisted the users to connect more to their family and support their daily lives. They found that total control over the house and its appliances was a secondary factor that made a system feel welcoming.

4. Methodology

4.1 Introduction

The following section describes the techniques used to evaluate the interface during its development. The observation, interviews and analysis methods were used in both studies. The low-fidelity prototype was used as a way to explore the design space and gain insights into user interaction habits and patterns at an early stage of development. It resembles the "User-Defined Action Studies" used in the report by Chong et al. [8].

4.2 Low-Fidelity Cooperative Prototyping

Low fidelity prototyping allows for a system to be explored and tested far in advance of its final release [34]. It is a low cost solution that can help give the participants a frame of reference in their mind. This can assist with imagining the interaction in their daily lives. Low fidelity prototypes can also be easily re-designed with low effort. In the paper by Antle [3] lo-fi paper prototypes "are selected to allow us to engage specific, and often quite abstract, aspects of the future situation of use". Given participants the freedom to explore their wished interfaces with less detail is described as the “horizontal relevance”. Giving them specific tools to reenact a proposed interface leans more towards “vertical relevance”. In early product development lo-fi is an invaluable tool and using both of these methods, vertical and horizontal, one can go towards a more well rounded interface.

For HomeNodes a low fidelity prototype was made using various stationary. The full list can be found in the Appendix.

A room already furnished with living room furniture was utilized for the prototype. This room was also used for the final system and user study. Seven students were recruited for the prototype participatory design session, and all studied computer science, thus they were quite familiar with technical terms and technologies. The session was split into three sections.

The first was a design exploration, whereby the participants were given the task of imagining how they would connect two or more household appliances together. They were free to construct any kind of system, including one that was not yet technically possible. The explorative design section was completed before the others in order to give the participants the opportunity to elicit their most intuitive understandings for connecting objects.

The second section used a paper prototype of a touch interface on the wall. Paper ‘nodes’ were placed near the objects and string was used to simulate the visual connection between devices. By sticking the string to the nodes, the participants were simulating the touch interaction and the physical effort required to connect devices within a space.

The third section was identical to the first, with the touch interaction being replaced with a smartphone interaction. The users would tap on the objects they wished to connect using the back of the smartphone to simulate NFC interaction and the string was placed to show the connection was established.

4.3 Observation & Interviews

Before the study began the students were asked to fill an ethics form confirming their permission to be recorded for academic purposes. During both studies the participants were observed in their interactions and recorded using video. In the first study this was done using a Logitech USB Webcam. A semi-structured interview was used during the session. The question list can be found in the Appendix. Before the users began their participatory design session they were asked a number of questions relating to their previous knowledge with pairing technologies and IoT. After completing each section the users were quizzed about their impressions and recommendations.

4.4 Findings

Of seven participants, two were female and five were male. The sessions lasted between 20 minutes – 45 minutes with an average of 36.5 minutes. To analyze the video, important events and comments were collected and made into a collection. From here descriptive analysis was done and ‘codes’ were built from the text. From this data it was possible to collect and examine the repeating patterns, interactions and sometimes themes of the interfaces explored. The analysis in both studies was done on a case level using descriptive analysis [20]. This method was also used for the full system users study, as it would make it possible to draw parallels and comparisons. For the low-fidelity prototype it was clear that the main talking points and patterns were observed during the suggested interfaces in the second and third part of the tests. This was to be expected and so therefore other topics serve as supplementary interesting findings. The direct interactions are not directly suitable for comparison with the main study, as participants were working with a completely different material, namely paper, string and sticky tack.

Four of seven participants found the touch interface most promising, with two of those also being slightly interested in the NFC approach. Two favored the NFC only approach and one preferred their own self-built interface.

From the multiple questions asked during the interview and the low-fidelity creation process, the topic of “Mobile” surfaced the most. The modern smartphone is very versatile, allowing for interactions to occur on its screen and through the use of its many sensors. The smartphone is already intricately used and understood amongst even those who are less technologically inclined. One participant mentioned already using the smartphone as a smart controller for home objects using the Raspberry Pi. The other participants imagined that the system they created or the HomeNodes system would appear on their smartphone in one shape or another. They describe interfacing additionally with the objects using the interchangeable and mobile interface of the smartphone, such as tapping on the NFC tags and receiving a smart remote for the object. Another method suggested was automation, whereby the smartphone would be able to automatically react and create a suitable usable control interface on the smartphone that corresponded with the system’s available objects without touching i.e. a radio controller for the nearby radio. Multiple participants remarked that the node and line interface would make sense on a touch screen which is portable.

The touch wall interaction (“Touch”) was the next most popular talking point. Touch interactions are already found outside of touch on smartphones (eg. touch tables, displays), making them known globally for various purposes (eg. ticket machines.). The interaction suggested to the participants (tapping two nodes) was well received, but some participants expressed the desire to ‘draw’ a line from one node to another. They also mentioned here that they wouldn’t care too much about dragging their finger along the wall. When drawing the lines using the string, two participants created orthogonal lines, such that they did not show the shortest path, but rather a guiding connection line. One participant stated that this was due to the obtrusions cause by the objects and that they would find it difficult to follow the lines without this layout. The activation metaphor from desktop computers was also noticed during the studies, as some participants initially wanted to ‘double-tap’ to activate something. Deleting the connection via touch was varied among participants, with the most common being the ‘slice’ gesture. Other suggestions included ‘clicking’ the line and also ‘pulling’ the line from one end of the connection. One participant was interested in a multi-modal approach, with touch and another method like NFC. While this was thought as unnecessary at the time of the low-fidelity testing, it was later found, due to technical restrictions and scaling issues, that a multi-modal approach was necessary.

Participants also found that changes and additions to the visual layout (“Additional buttons etc.”) would also be required to make the system function as they had imagined. By adding additional node points surrounding the main node it would be possible to separate areas of the graph such that if one device is turned on, the other connected nodes are not necessarily also turned on. This is illustrated in the diagram Fig. 3.

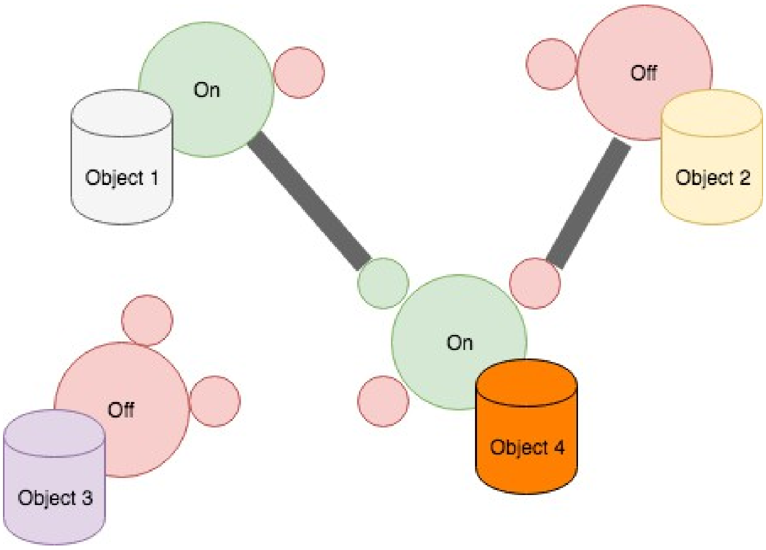


Fig. 3 – Object nodes with smaller logic nodes

Another participant constructed the idea of allowing for a 'traditional' home automation system to blend with the HomeNodes system. This meant that one node next to the device could be connected to a list of smaller nodes located nearby in the interface. Colour would be used to differentiate objects and their state. This idea is illustrated in Fig. 4

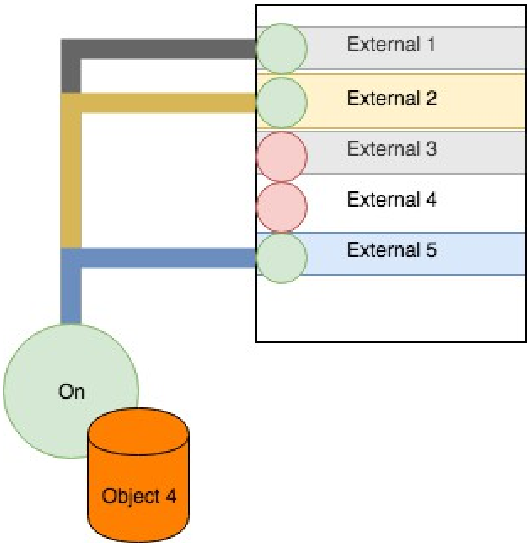


Fig. 4 – Coloured lines and smaller nodes

Other participants discussed similar systems to the previous, where the rooms are clearly labelled with the list of connectible objects within. An important issue was noticed by a participant, where they tried to connect more than two object on a single horizontal or vertical axis. Lines in this case would overlap, and users would find it difficult to follow the connected directions. This important issue influenced the design of the curved lines in the final system.

The final participant in the low-fidelity prototype sessions made the suggestion of returning to physical ubiquitous computing. They described the use of physical buttons attached to the device which would both turn the device on and at the same time enable the connection state to another activate product. Coloured LED lights would then identify to which channels the objects belonged. After discussion it was agreed that this would best work with as few devices as possible, as too many indicators and lights would only complicate the visual connection understanding.

“Gestures” was also a popular topic, especially at the first explorative stage, where participants were able to imagine any kind of system with any imaginable technology combination. A participant wanted their personal system to allow them to point and snap at devices to connect and activate. They also wished to delete lines from a distant position, like slicing the visual line from their line of sight. Touch and other interaction gestures were suggested in the other stages, where one participant suggested that lines could include directional cutting gestures with the finger on the touch interface. When one would cut in a certain direction, the connection would be lost and only one device would turn off Fig. 5.

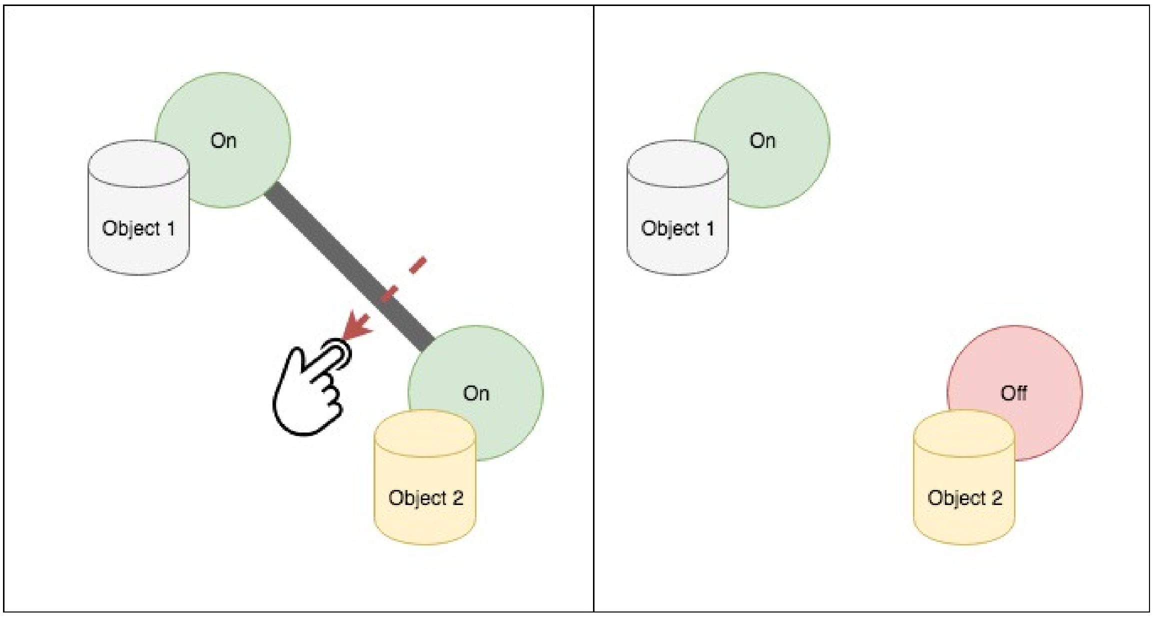


Fig. 5 – Deleting line gesture (left), lower object turns off (right)

For the NFC interaction, the final participant suggested interacting with a particular part of the home appliance that would be assigned to a function i.e. on, off or start connection. The mobile phone could also be pre-defined to a desired holding position for functionality. The participant suggested using the device’s physical state to inform the system of its status and the next function. For example, this meant that if the washing machine door was opened, the connection to all other connected devices would disappear.

"Device hierarchy" and "continuous flow" were topics raised that did not repeat often in the prototype phase, but they do pose valid points for creating an interaction to connect a web of things. "Device hierarchy" was brought up by two participants and is classified as the separation of devices hierarchy (slightly different to the multi-node separation explained earlier). In the hierarchical system, if one object was set as the 'primary' device it would influence all connected 'secondary' devices. However, if a secondary device would be activated, it would not influence the primary device. This concept does address the issue of unintentional device activation, even without the proposed HomeNodes visual system. More conceptual interfaces would need to be implemented and prototyped to verify the validity of having a hierarchical network as described. Node hierarchy was not seen as a requirement for the later system, as unintentional activation or deactivation of devices in the HomeNodes system was not detrimental to the functionality of the devices. In addition, including the simpler functionality without hierarchical communication would allow for the 'base' system's connection/logic understanding to be explored, be it expected or unexpected. "Continuous flow" was an interaction method that was not noticed initially in the final system analysis amongst certain people. The footage from the paper prototyping sessions was then reviewed, where it was possible to see the same interaction occur with paper and string. When given the opportunity, one participant connected three objects together in one continuous 'movement'. This was noticed more often in the final system analysis, as the participant's were not as occupied with physically attaching the string near to the devices.

The purpose of the paper prototyping sessions was to gauge the viability of the proposed interactive systems; NFC and Touch. The explorative aspect of the sessions allowed for the participants to give their opinions on what a connected web of things could be. Most participants were comfortable with and understood the connecting metaphor, so it was decided to start the development of the system with their suggestions and thoughts as influencing factors. The paper interface examples are shown in Fig. 6.

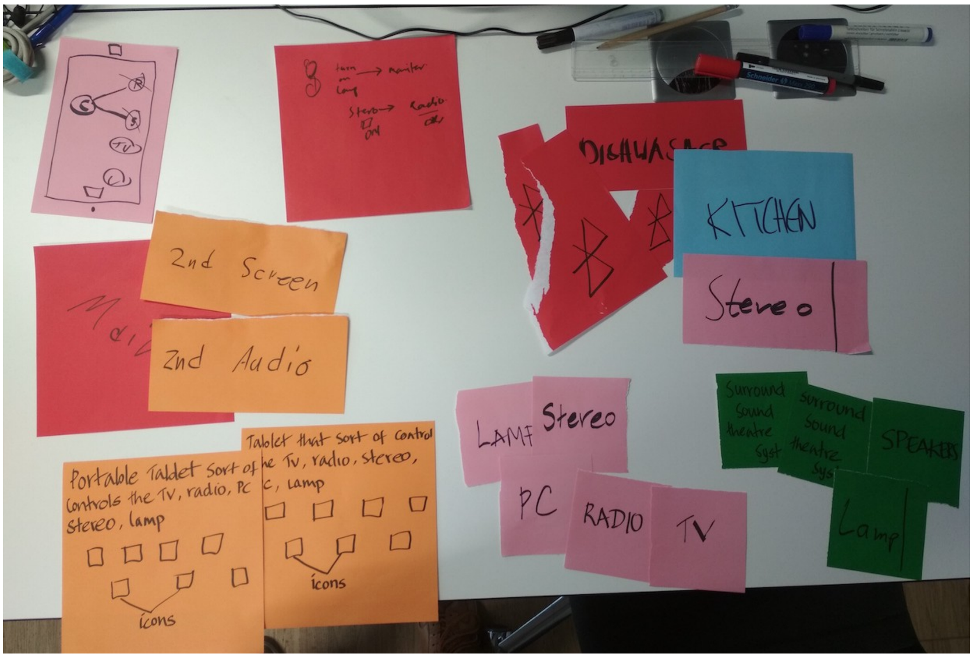


Fig. 6 – Collection of interface elements from low-fidelity prototyping sessions

5. Implementation

5.1 Designing an embedded interactive interface

From the research completed in Section 3.3 of this paper it was clear that a lot has already been done in the connection of wireless home appliances. However, it is also clear from the design space of IoT technologies that there exists a culture of ‘remote-controllers’ where convenience and customizability overshadows the existing physical relation between devices. Reality Editor nicely attempts to bridge this gap, by using the smartphone to configure and view the integral connectable parts of objects.

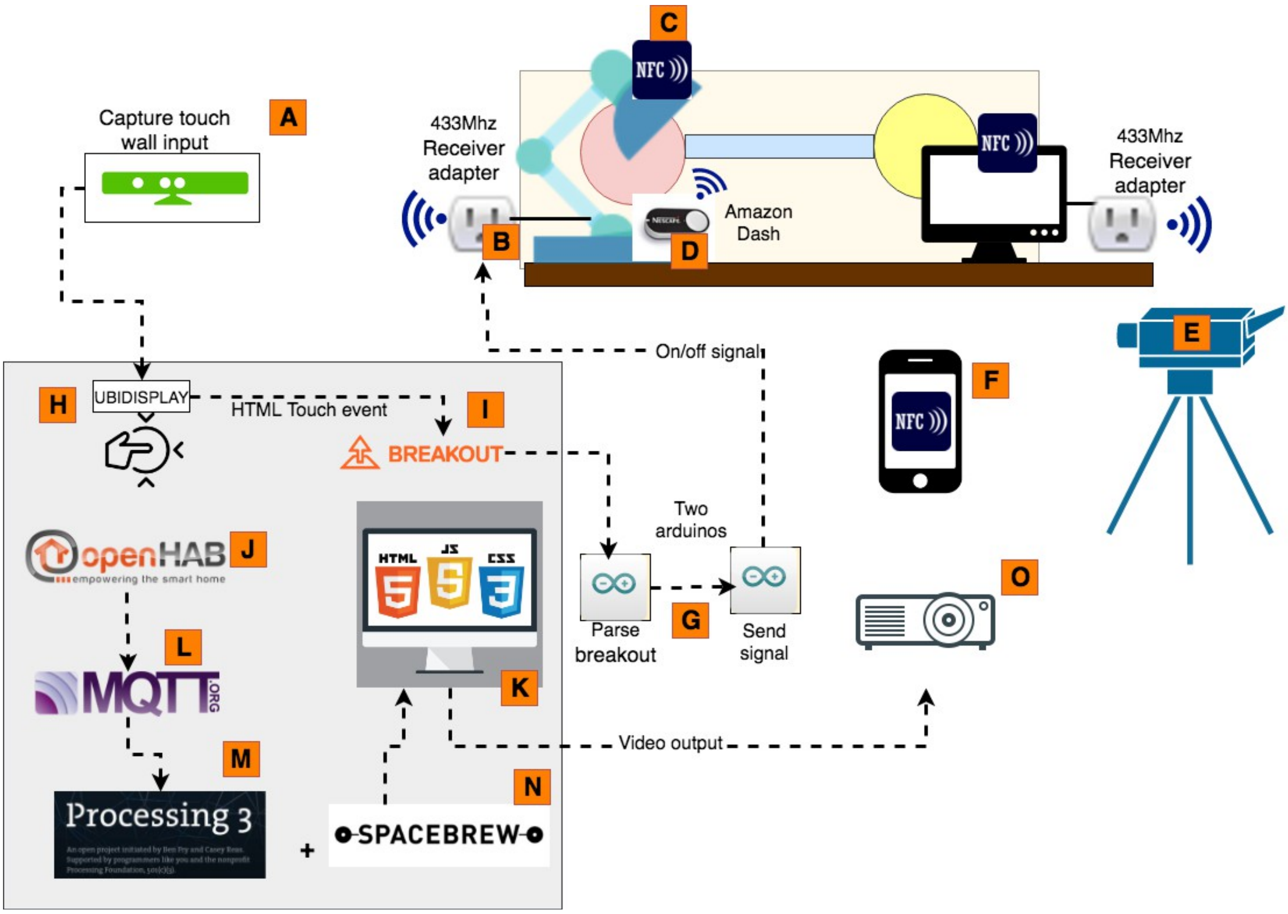
It is also suggested from the results of previous research that people have learned and are already used to certain interaction conventions. Those who are already used to interactive objects expect them to satisfy and become a truly useful appliance worthy of their money [4]. Hence, the need for a new interaction to assist in the convenience of connecting devices might not be fully accepted by the user. Nevertheless, this thesis aims to explore the IoT design space, which is still finding its foothold in today’s society.

As described in the earlier sections, the visual interface was inspired by Reality Editor. Connecting nodes via lines is a well understood metaphor within visualization, computer science and mathematics for a direct connection. If no other information is provided, one can suggest that one node is in some way related to the other node. Reality Editor, being developed over a long period of time, evolved to include detailed electronic component descriptions, animations to show flow control and a logic system to make compatible electronics intricately dynamic.

5.2 System Overview

The entire HomeNodes system is composed of multiple interconnected parts and software toolkits. The primary function of most of the toolkits is to send messages to and from the currently active web application. Much of the technology, like described in the paper by Blackstock and Lea [7], automate the process of setting up a local server and provide a GUI for interaction. The steps of setting up the system is listed in the Appendix. The background processes completed by the software listed are outlined partially in their respective sections later in this paper.

The entire system can be viewed in the diagram in Fig. 7. Table 1 describes each part labelled in Fig. 7.



ID	Name	Description
A	Microsoft Kinect	Gets a video feed of the projected wall. Utilized by UbiDisplays.
B	433Mhz Radio Frequency Adapter	Radio frequency adapter with a build-in code for switching the adapter on and off.
C	NFC Tag	Tags placed on the object that represent the devices identification and interaction point.
D	Amazon Dash Button	Button used to switch devices on and off. These are meant to replace the devices default physical switch. Delay of one to two seconds.
E	Interview camera	Camera/smartphone used to video record the interactions and interviews for later analysis.
F	HTC Desire 610 smartphone	Smartphone with NFC enabled and Sensors2OSC installed.
G	Arduino Deumenilove pair	One to parse the input signal from Breakout and the other to send the RF signal.
H	UbiDisplays	Software to calibrate touch surfaces.
I	Breakout	Software that creates a bridge between web elements and Arduino code.

J	openHAB	Open-source home automation software to manage and control smart devices and send signals.
K	HomeNodes	Created with HTML, CSS, Javascript and libraries. Running on a Macbook Pro 2009.
L	MQTT Brokers and Client	HiveMQ used as MQTT broker to send MQTT messages from openHAB to Processing
M	Processing	Receives the OSC signals from Sensors2OSC and the MQTT signals from OpenHAB, then forwards them to Spacebrew
N	Spacebrew	Parses signals from Processing and other sources and forwards them to HomeNodes
O	Projector	Projects the interface onto the surfaces near the home appliances

Table. 1

5.3 Communication with home appliances

With most older home appliances, if the electronic control boards do not have any integrated communication protocols then it is seldom possible to interface with them from an outside source. Editing the properties and functionality of the device would often require the owner to take it apart and potentially reengineer it. An interactive method for most wired home appliances is the power socket adapters. These adapters are most often used to control, measure and vary the electrical input to the supplied appliance. This of course does not always apply to battery powered devices, as they can run off their own power. In this case, just the ‘charging’ state would change.

Modern wireless power adapters are made in various ways and use different protocols. Radio Frequency (RF) power adapters are quite cost-effective ways to turn on and off a device. They often come with a remote to control a set of adapters. Due to the small number of adapters, it is still quite reasonable to assume that people can remember the objects and their adapters. There is of course the option of labelling the buttons. Labelling remotes and placing them in their respective rooms has the same end functionality as HomeNodes and is also less strenuous than physically interacting with the devices. HomeNodes extends the technology and offers an alternative perceivable interaction method that may benefit certain use cases.

Another option is a WiFi enabled power adapter. Modern versions now have pre-built applications that can be used to switch the objects or change their properties. An example for this is Homematic [52]. Due to its more robust feature list, adapters like this can be more expensive.

The decision to keep the functionality as binary on and off meant that RF power adapters were the most sensible, as programmable RF transmitters exist with systems such as the Arduino. Cheaper Chinese manufactured WiFi adapters are available for purchase. However it was not known, at the time of writing, if the communication protocol was available outside the smartphone applications provided with the devices. It was later discovered that additional antennas were required to extend the range of the RF transmitters (see Section 5.4.3), but this still would work out less expensive than the fully integrated WiFi systems. The RF adapters used in the system each had a specific code that could be transmitted to activate them. A RF sniffer sketch was used for the Arduino with a receiver to find out the necessary codes which the RF remote transmitted [28].

5.4 Exploration of further interactive technologies

An early design decision was to have some sort of visual control for household objects. In addition to touch and NFC, gesture and motion control were also considered as interface controllers. The Microsoft Kinect is typically used as a game controller to control an avatar or cursor on screen from a distance. Open Source SDKs allow for skeletal tracking to also be done using software libraries. "From a distance" controlling was considered and tested using the libraries available for Processing created by Daniel Shiffman and Thomas Sanchez [35]. Before development using the UbiDisplays program began, another touch enabled wall interface was explored. Created by Jason Beck [5] it used Processing to create an interactive touch wall. As of writing the website post is offline.

Another option considered for distance control was optical recognition. Rather than have the Kinect track the user's skeleton it would track what is visible in the user's hands. The objects in the user's hands could range from a marked tracker to a brightly coloured bracelet. The reasoning for the bracelet was to allow for users to still be able to use their hands in between interface interactions.

5.4.1 Kinect and UbiDisplays

The Microsoft Kinect has two cameras and one IR sensor. The algorithms used with the Kinect can transform the captured video and IR data into depth information about the scene.

UbiDisplays is an open-source desktop software that makes use of the Kinect data to judge the spatial placement of a user's hand near a flat surface. The interfaces can be simply built using web programming languages such as HTML, CSS and Javascript. The developers recommend using the web-enabled touch and mouse interactions built into web standard languages, which also mostly function in their software.

There are a few disadvantages of using the UbiDisplays program. They are as follows:

Not currently maintained: While the current release of UbiDisplays is in a working state, it is not free from errors and crashes. For running the HomeNodes system a MacBook Pro 2009 was used with a Bootcamp Windows 7 partition installed. The laptop used in this project for the HomeNodes project is not modern in terms of its processing power and the UbiDisplays program is the most computationally intensive program running in the project. The crashes most often occur due to the incorrect placement of the interaction surface in the "Surface Editor". Should the display area exceed the boundaries of the camera feed or overlap with too many non-flat surfaces (white interference areas) then the program crashes. In addition, the sample code given with the UbiDisplays program uses the Javascript deprecated method ".bind()" to run a touch event. This makes it then more difficult to match to modern Javascript touch interaction techniques that make use of other methods.

Small interaction area: the Kinect camera is required to be quite close to the projected surface. This means that the interaction area is limited to the frustum of the camera. During development a "Nyko

Zoom Lens" [61] was tested with the Kinect. The product description states it allows for the play area to be reduced "up to 40%". The lens did work with UbiDisplays, but didn't offer much in terms of scalability on the wall. The white interference persisted around the borders of the calibration video feed, meaning that the calibration area was increased slightly. However, this was unnecessary in the final system version, as the most important area for the UbiDisplays interaction was one portion of the wall.

Configuration: Unless the Kinect camera is not moved from a static position for all interaction sessions, then configuration is almost always required. Fortunately the configuration process is not difficult and requires only four points to be clicked on screen.

Outdated debugger: The UbiDisplays program uses the outdated Awesomium browser to display the HTML in the program. This browser also comes with a debugger, which is also somewhat outdated. The debugger does not show returning console information and as such is only really useful for visually highlighting the HTML page elements when designing the interface. Therefore special Javascript and jQuery libraries and APIs that would have relied on receiving critical developer console information during full system runtime were generally avoided. The functionality was always tested in a working developer console before making it to UbiDisplays for final testing.

5.4.2 Near-Field Communication

NFC (Near-Field Communication) is a communication protocol that operates in very close range (within 4cm approximately). This close range makes it very analogous to touch. Naturally, this touch is limited to the place where the NFC tag is placed. It is used quite often in administrative or employee identity cards. NFC is thus often used to identify something or someone. This identification is clear once an NFC reader is used. HomeNodes uses the Android application "Sensors2OSC" [57] to identify the NFC tags. This application is the most straightforward way of sending an OSC signal through NFC identification, at least during the time of writing. The application sends the brand ID of the NFC tag over OSC, meaning that separate NFC tags must be purchased to make use of the default functionality.

5.4.3 Discoveries and design decisions during development

Initially the system was just to use touch as the interaction, but after some testing it was clear that the scalability of the system was quite narrow. This was essentially due to the small size of the projection touch interface and the requirement of the Kinect to be close to the wall. In addition to this fact, it was found that objects placed directly in front of the UbiDisplays surface would interfere with the interaction, causing errors and inaccuracies with tracking. Therefore, as scalability was a driving factor in the work from Reality Editor, it was decided to use NFC to increase the scale of the system to a more reasonable size.

UbiDisplay, being a hardware and graphically intensive program, was found to work better when the interaction screens were kept at low screen resolutions (Fig. 8).

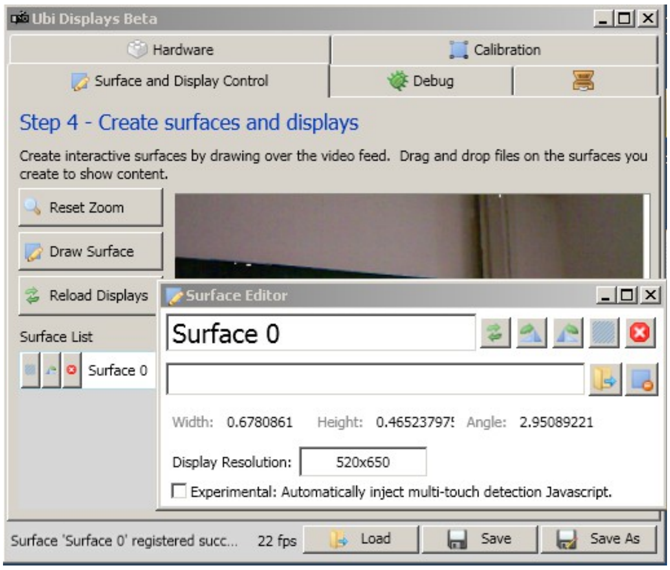


Fig. 8 – UbiDisplays Surface Editor with display resolution configuration

Building the interface in a desktop environment did not necessarily equate to what would appear on the UbiDisplays. If the interface was made with high resolution while developing the front-end, the computer would require more computation and the interface would lag. Therefore it was important to keep the screen resolution relatively small and develop the front-end for this.

In early prototypes of the interaction system, it was planned for the user to be able to draw or drag the line between the nodes to connect them. While quite straightforward with mouse and traditional touch interaction, allowing for the same methods to be used with UbiDisplays was more complicated.

A short-throw projector was tested with the system without using mounting equipment. It was placed at waist-height parallel to the wall and home appliances. This proved to be problematic however, as the lower angle of the light beam caused for larger shadows to be created, blocking the interface. The normal longer range projector was used finally for the user-tests and placed on a sofa in the room. This still caused shadows for people walking in front of the interface, but they were non-static, making it a surmountable distraction.

Another method considered for NFC identification was the Android application “Tasker” [59]. Using a companion application it is possible to run a Tasker task when an NFC tag is identified. This idea was later dropped, as it required too much inter-app operability and OSC communication was not assured using this method.

Before moving to physical replacements for the object’s buttons, a program called Protobject [6] was tested in conjunction with HomeNodes. Protobject is an application on desktop and smartphones that allows one to get a video feed from a smartphone and run image/state analysis with the video feed. The user assigns a still image that represents the state of an object eg. on or off. This information can be send through a WebSocket to a web application. This functionality was tested but dropped, as the logic of switching devices states would not work with the RF adapters.

For example, if one RF adapter was set to the ‘off’ state, it would not be possible to manually flick the built-in switch and turn the device on. Nevertheless, Protobject in an interesting program that could potentially be a low cost solution to monitoring certain home appliances.

With current home appliances that use a switch or button, it can sometimes be complicated to interface with the appliance, replace its switch or monitor its power consumption. Electronic adapters and home automatic technology such as the Homematic [52] do allow for electrical monitoring, but in the case of HomeNodes, was somewhat unnecessary. The Amazon Dash button was chosen as it allowed for physical control over the devices in a manageable way within the system. They are quite affordable miniature internet-enabled devices, making them ideal for the replacement of existing buttons. However, the Amazon Dash button requires the use of the Amazon smartphone application. This application can only configure with a normal home WPA2 or similar WiFi network, so a WiFi Enterprise network may need additional configuration. Therefore, a personal WPA2 hotspot must be established to use the HomeNodes system, such as a smartphone or alternative router.

Two Arduinos were utilised to send the logic from the webpage to a RF adapter. This was due to the two Arduino libraries (Breakout and RCSwitch) not operating well together. The two Arduinos required different baud rates to send and receive data. Therefore the solution was simply to send the digital signal to the analog input of the other Arduino.

For testing purposes, “Chrome Remote Desktop” [48] was also briefly used. This allowed for the HomeNodes interfaces to appear on a smartphone or another Remote Desktop enabled device. The interaction from desktop to mobile did not always meld fluidly, but using the smartphone it was possible to connect the nodes as if one was controlling it on the host computer. Because the Remote Desktop is capturing the screen, the size of the captured interface does not always scale well to the mobile screen. Despite the interface elements not being “mobile ready” or “responsive”, the HomeNodes was still partially usable. Since the nodes (and Virtual Devices) were large on the original device, it was possible to activate them with finger pressing. Therefore, a Remote Desktop is potentially a viable option when prototyping a multimodal interface.

During the development stage where Spacebrew was tested, Node-RED was also briefly explored [54]. Lauded on its website as a form of “flow-based programming for the Internet of Things”, it is already quite an expansive connectivity tool for connecting services and some smart devices. Built on NodeJS and Javascript, it was used briefly tested during development along with the use of the Amazon Dash buttons and MQTT. From the testing it was found that Spacebrew, in combination with OpenHab, was the most straightforward solution for the Web of Things implementation.

5.5 Front-End

The front end of the HomeNodes system was inspired by the Reality Editor. The positioning of the nodes in the interfaces was dependent on the positioning of the objects in the environment. The reasoning for this was the early prototypes of the HomeNodes system. In this early version of the system the nodes could actually be touched using UbiDisplays. This, through numerous iterations, was best accomplished through the use of SVG circles and lines. As these SVGs require multiple coordinates to set the positions, transforming these coordinates in real time using UbiDisplays presented a much more complicated interaction and programming task than was needed. This decision meant the positioning would become hard-coded. SVGs also worked the best with UbiDisplay in comparison to other web elements. UbiDisplays does seem to use an older Google Chrome browser variant (Awesomium), meaning more involved CSS or Javascript interactions may not work as well in the UbiDisplays environment.

The projected interface is made of three components: the touch-enabled left screen with virtual object image slideshow and line-deletion bin (“index.html”), the right screen with circular nodes and lines (“nfc.html”) and “hello.html”, the interface emulating the BreakoutJS clicks and also used for debug purposes. “hello.html” is a modified version of the default sample code given with BreakoutJS program. Because all HTML pages need to be on the same browser to communicate, a black square was placed in front of the default given GUI from “hello.html”. This is because the visual interface is not actually needed by the users and the colour black does not “appear” in the projection and blends with the projected surface.

Index.html: During development it became obvious that one might consider external objects in an IoT scenario. In traditional IoT or Home Automation systems the objects in the house might be represented only by name or by some sort of icon. The purpose of the image slideshow is to return the visual familiarity of the object to the user. The user can control which virtual object appears using the two buttons at either side of the displayed object, “L” for left and “R” for right. There are only two objects in the interactive slideshow, meaning that technically only one button would be needed in this case. However, it was built like so to test the acceptance of the type of interface with the participants. One nice alternative to simply having a picture within the object slideshow would be a live video feed of the objects within the house. According to the UbiDisplays authors the best practice for the GUI elements is to make them as large as possible. This impacted on the choice of having such a slideshow and bin icon. When the bin icon is clicked it briefly changes to indicate clicked feedback, with a multi-coloured representation of the HomeNodes connection lines being placed in the bin. Inactive versions of the SVG elements from “nfc.html” are also present in this webpage. They are simply there in order for the connecting lines to match up to the parallel screen (Fig. 9). The on/off button works much like the other switch buttons in the system, acting as a toggle for the connected real or “virtual” objects. In the current version it is not possible to connect the two virtual objects to one another.

Fig. 9 – Red box indicates the point where the UbiDisplays surfaces meet. The coordinates of the visual elements in the HTML and CSS are off-screen and used to align both surfaces.

Nfc.html: There are four nodes placed in a particular formation on the webpage. This formation corresponds to their approximate position in physical space when the webpage is projected on the wall. Once the Amazon Dash buttons are clicked the red nodes on the screen change from red (“Off”) to green (“On”). Tapping on the NFC tags of the real objects places a blue border, indicating activity. Once another object is tapped a line is created between the nodes. This line is bi-directional, in contrast to the Reality Editor, which shows the acting directional flow of the connection. Thus, if more than two devices are connected and switched on or off, the connected nodes follow suit. Like “index.html” the external node is placed off-screen to allow for approximate line alignment between nodes. The lines connecting physical objects are also arbitrarily coloured. This was done in order to make it clearer to the participants that there were differently established separate connections between devices, and also during development to help organise the logic. The lines connecting the external virtual devices were all coloured grey, as each of the four lines were included once in the code. The grey lines only appeared when the virtual object was visible on the slideshow, as changing the external lines’ colours dynamically was not seen as necessary in the currently developed version. This also gave the opportunity during the study to see how users would react with the difference in object feedback and interaction.

5.6 Back-End

Multiple different local inter-browser communication methods were used in HomeNodes. The final collection of communication libraries was constructed in such a way that almost each communication library has its own specific messages that correspond to a task of the system. The following is a list of the Javascript libraries and their purpose within each webpage.

"*divconnect.js*": This is the primary collection of logic, functions and commands that controls the system. Here exist many of the boolean variables which indicate the connection status of the home appliances. Connections to the UbiDisplays program, Spacebrew and the Arduino BreakoutServer are established when the document loads. Here the program runs the functions that switch boolean states of devices, checking them against one another and changing the visual elements on interaction. The largest portion of the code is managing the interoperability between devices states, done primarily with 'if' statements.

5.6.1 Web Technologies and Libraries

The following Javascript libraries establish the connections and communication channels to the outside programs and other webpages within HomeNodes.

"*Breakout.min.js*": This library communicates with the Arduino server located on Arduino A (Fig. 1). Messages are sent from "hello.html" to the Arduino which then send a signal out via the multiple digital outs. The digital-outs are then received by the analog-ins of Arduino B. Depending on the input signal received the connected RF transmitter either sends an On or Off signal to a corresponding RF power adapter.

"ubidisplays-multitouch-0.8.js": This is the library used to establish the surface dimensions, settings and touch functions run by the UbiDisplays program. Like the other libraries, it needs to be imported as a Javascript asset and the necessary UbiDisplays base code included when the page loads.

"*sb-1.4.1.js*": This library and the additional Javascript code is used to connect to the local Spacebrew server. Once connected it can appear alongside other Spacebrew enabled webpages or programs. One can then send and receive messages by using the supplied Spacebrew functions. I found this to be a very intuitive an invaluable library for message sending between browser webpages.

"*BNCConnector-compr.js*": This Javascript library is offered as a cross-browser communication platform that doesn't require any additional setup other than the setting of unique variables. The author has "created [an] implementation of BNC networks model with [a] simple TCP/IP layer, that...will use browser's cookie object...as [a] transport packet." [47] It is therefore using a commonplace storage method on browsers to send messages. This library was chosen initially during the phase of HomeNodes when only touch interaction was used, thus requiring a system that worked simply across browser windows. It was kept as a method of communication in the final system for the same reason, in this case with NFC being the alternative to touch interaction.

5.6.2 Other programs

OpenHAB: "OpenHab" [55] is an open-source home automation application available for desktop and mobile. It has multiple add-ons that allow for networked devices to connect and be modified. One such Add-on (or "Binding") is for the Amazon Dash button. This Binding listens for the MAC address of the Amazon Dash button in the network. The MQTT Addon was used that gave OpenHab the properties of an MQTT client. It is possible within OpenHab to create "rules" that work as logical functions. With both the Dash and MQTT Addon, respectively, it was possible for an MQTT message to be sent when the Amazon Dash button is pressed.

HiveMQ: "HiveMQ" [51] is an MQTT broker that acts essentially as a server for registering ("subscribing") and de-registering MQTT clients. Once a client is subscribed it can send or receive MQTT messages to or from another client. The company offers a six-month trial where one can locally host the MQTT broker.

Processing [56] is another useful IDE (Integrated Development Environment) used for the HomeNodes project. It was useful in its support of both Spacebrew and MQTT, allowing for quick transformations of message data from one format to another.

"*SpaceNFCSender.pde*": The first version of this Processing sketch was just used as a means of receiving OSC data from the Android NFC application. Eventually Spacebrew was included which allowed the communication with the main Web application. While initially it was attempted to send MQTT messages directly to the Web application, it proved much more straightforward to use the MQTT code provided with the said library and receive signals and forward them through Spacebrew. The OSC messages are received from Android as large float values and due to the Sensors2OSC limitations, can only be sent like this for a single brand of NFC tag. The MQTT messages are converted in Processing as a byte array in the sample code. From this it was possible to use the first index of the array as the identifier in Processing. However, this is not realistically scalable with the addition of more tags and the byte array would need to be parsed differently, as some messages may be received with matching byte array indexes.

Altogether in HomeNodes, two clients are connected to the HiveMQ broker; OpenHab and Spacebrew for Processing. The MQTT messages are sent from OpenHab, through HiveMQ, to the subscribed Spacebrew application in Processing (Fig. 10).

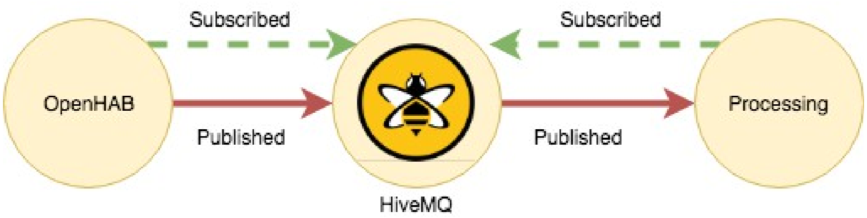


Fig. 10 – MQTT communication channels in HomeNodes

5.7 Technical Issues

The HomeNodes system was built to a usable state that allowed for simple semi-guided user studies. As a commercial product, HomeNodes would need the inclusion of further bug-testing, improved security and an updated user interface. The current implementation is best done on a locally hosted machine, but many of the communication systems and web technology would benefit from remotely hosted versions.

Before any user tests were even conducted, it was clear from the system that people's bodies would be blocking some of the projected interface. This was not considered as a hugely pressing issue, as the 'blocked' portion of the interface acts more so as a confirmation of the 'connecting' actions that were completed with the technologies. However, this still sometimes meant that there was a lack of physical feedback and therefore additional confirmation of the user's actions. More physical effort is required to perceive the visual feedback and so HomeNodes may certainly benefit from an always visible display method.

The design decision outlined in Section 5.4.2, moving the Kinect facing at an angle to the wall, was the most reliable way to simply setup a touchable UbiDisplays screen. The lack of interfering objects meant that the user can emulate a touch interface without requiring a specialized surface or equipment, respectively. However, this did not make the touch interface free from problems. If the Kinect was not placed sufficiently in the pre-calibrated position in front of the wall, the UbiDisplays program had to be re-calibrated. The subsequent touch interface was usable, but not always as intuitive as it would be if the same interface was presented on a commercial touch display. If the user's fingers are slightly off center or two UI elements are placed too close together, false clicks can occur. Some minor bugs are also noted in the pilot study in Section 6.2.

6. Evaluation

6.1 Study Design

The study, like in the low-fidelity prototyping sessions, took place in a small living space between two offices. This space resembled a small living room, making it suitable for the experimental setup. Most electronic components were visible to the participant and not hidden. The exception was the Raspberry Pi 2, slightly hidden behind the computer monitor, which was running a looping video in order to simulate a live television.

The studies lasted between 15-30 minutes with an average of 21 minutes. This was considered reasonable, as the system doesn't include functions beyond a turning on and off devices and interaction methods. There were 13 participants in total, with 11 being male. It should also be noted that, for most users, English was not their first language. The participants actions and comments during the study were recorded using a smartphone mounted on a tripod to record video and audio. The participants were given an ethics form to sign if they had already not given permission to be recorded in the low-fidelity prototype study. The purpose of the study was to simply gauge people's interaction approaches and impression of the system. A collection of recurring patterns was built to be compared to the findings of the low-fidelity user studies.

6.2 Pilot Study

The first participant in the final user was brought in initially as a pilot study participant. The proposed study design was tested and there were some minor inconsistencies found:

1. The radio logic node in "*divconnect.js*": the user is able to turn on two devices using the radio, but the radio does not switch off when another connected node is switched off).

2. The virtual "on/off" switch: does not visually switch visual states correctly when switched from a connected physical device. This is likely a bug with the correct usage of "*BNCConnector-compr.js*" in which the other directional message sent (nfc.html to index.html)

Despite these the participant felt the system worked as it should and the small bugs did not influence their understanding and interaction with the system very much. Thus, this participant was treated as a full study participant and their feedback was included in the evaluation.

6.3 Procedure

At the beginning of the study the participants were given a short demonstration of the system. Arguably this may have introduced some bias into the qualitative data, as the participants were simply able to shortly follow instructions rather than explore from the beginning. This training was seen as necessary, given that giving hints as they try to discover the interface would likely distract from their task and potentially frustrate them. Special introductions were particularly needed for the UbiDisplays program, as the feedback was not equal to the likes of a traditional touch-screen. The participants were also clarified on what the NFC technology on the smartphone was if it was unclear to them. Delays from the touch interface and Amazon Dash buttons were also clarified before or at the beginning of the exploration phase.

The demonstration for the participants was ordered by increasing difficulty (listed below). The following tasks allowed them to explore the demonstrated techniques and they were free to complete them in any order they wished:

1. Turn on the devices (using Amazon Dash button)
2. Connect two or more devices to each other (using the NFC enabled smartphone)
3. Switch between 'virtual' home appliances using the touch wall
4. Connect a 'virtual' home device to a physical home appliances
5. Turn on a physical device when a suitable connection was established
6. Turn on a virtual device when a suitable connection was established
7. Delete a connection between two physical devices using the smartphone
8. Delete a connection between a physical and virtual device using the smartphone and touch wall

After their exploration of the system was deemed as complete, the participants were asked some short questions. These questions can be found in the Appendix and related mainly to their first impressions of the HomeNodes system, how it was understood and how it would impact their daily household appliance interaction, in particular with other people.

6.4 Findings

The analysis for this user study also made use of the same method from the low-fidelity prototype earlier in the project. The following section is a description of the reoccurring topics sorted by topic frequency. The frequency is of course influenced by the questions asked at the end of the study. In cases where topics were similar or occurred only once, they were included in the topics of more frequent topics. This list can be found in Appendix A.4. Within the list are also notes from the observer which are discussion points noticed while doing the analysis.

Blocking the interface

From the video analysis and the comments from the participants it was clear that the placement of the projector impacted on the perceptual ability of the system. Participants were interacting in front of the projector, thus obstructing the beam and causing some portions of the screen to be covered with a shadow. This act of "blocking the interface" caused the participant to move in a way such that they could see the interface and the results of the NFC interactions.

Participant 2 said: "Visualisation was quite good. There were some parts where I was like right now [blocks projector]...where is the lamp is connected to?". The participant's "connection understanding" was therefore influenced by the occlusion.

Participant 3 wouldn't want to use the interface in their home if such a display method was required: "Main reason to not use it would be obstruction".

Participant 4 remarked: "That is one flaw…it would be better if there was no obstruction".

"Obstruction…unless you had the vibration, you wouldn't know at all if they are connected. It would be better if I had a projector on me maybe."

Other participants would quickly say they are in the way and would proceed to move out of the way or noticeably move out of the way. Participant 9 noticed this especially:
"Might be a problem if it's not within the line of sight. You have to move physically".

This indicates the participant's acute awareness of their occlusion of the interface. This fact was explained to the participant and at the end of the study there would often be a short discussion on the alternative methods for displaying the interface. The discussion (Section 7) and future recommendations (Section 7.1) describe some of these alternative methods that were discussed.

Understanding the purpose of the connections

The second question of the interview inquired about the participant's understanding of the connecting lines and its relationship to the physical world. Some participants remarked on this already during the study, making it the next most discussed topic.

Participant 2 simply said: "With the lines visible it is clear enough".

Participant 4 gave the answer during the interview: "That's cool, to save time if you want to connect and [control] all devices with one device".
They continued later by describing very much the purpose of the system without having been prompted very much since the beginning of the study session:
"It's better if you want fast interaction with world around you, if you don't want to use a screen all the time. It's kind of a cool way to connect the devices without having to enter any commands or having to deal with a touch screen."

Participant 5 was noticeably surprised when testing the connections between the virtual devices and the physical devices. Once a connection was established they switched the virtual devices, noticed a grey connecting line disappear, then shortly afterwards understood what had just occurred. They were pleased to see the relatively swift connections being established: "Cool…immediate connections and nice feedback."

When deleting a line, Participant 6 noticed without prompt that the period of activation between two nodes had stopped. Shortly after, they retried the deletion action, successfully deleting the line as intended.

Participant 7 talked about their existing understanding of their own household appliances, mentioning the physical connections (such as cables) that already occur between devices that may not be immediately visible:
"The connection I have between devices [at home]…is missing….But here it's clear".

Participant 8 could operate the system, but was overall unsure about its true necessity. The shelf holding the radio actually occluded the radio and they mentioned that without being notified they wouldn't have noticed it:
"I'm not sure I can…yeah I can sort of map them."
"I would have missed the fourth one [Radio]."

Participant 10 said: "Nice how the connection between the different devices works".

Participant 12 described their experience trying to visually make the relationship between digital and physical, assigning identifications to the placed objects:

“I first have to identify this target and then I identify the corresponding target on the wall...They are close in this case so it is easy”

Participant 9, like Participant 12, gave the valid point of the system still being less about the ability to physically interact with the devices, but more about the ability to perceive the system and its parts:
“Usually we deal with the physical things…now it’s changing the concept from physical to perceptual”.
“I don’t know if it’s about the place or the thing”. Regarding the connection of lines using the interface they said: “Connecting is quite simple”.

Without a more visual or sensory clue as to what the connections were, Participant 13 couldn’t internally assign a purpose for the connections between the devices: “It was complicated at first… especially the connection, I didn’t understand why”.

Deletion confusion

As mentioned previously, having the deletion function include a touch button and timer was due to the problems foreseen while developing the touch-only interface. Thus, simply with the inclusion of an extra step, intuitiveness and swiftness becomes worse in this case. Participants during the study mostly realized and succeeded in the task after showing and explaining to them the deletion interaction a second time.

Participant 3 had said during the interview: “...what I found it hard to get was to first select and select and then touch the bin”

Participant 4 gave the feedback: “Deletion…if you didn’t tell me I would think it was not responding”.

While Participant 9 had earlier said that the connection was simple, at the same time they remarked: “It can be tricky to delete the lines…”

Participant 12 touched the delete icon before selecting the lines. This behavior suggests another deletion method, which would be that all lines and nodes become selectable in a so-called “deletion mode”. This may be useful for a HomeNodes system populated by multiple lines, potentially speeding up the deletion process.

Good for shared use

The last question at the end of the interview enquired about using the system with other people in a shared house. Operating the system is open to multiple users and does not currently have built-in profiles or account settings. The question could also have lead to responses on collaborative home automation.

Participant 3 included a caveat about personal space while sharing the system: “If I use the system with other people then the interaction space would need to be quite big”.
“If I’m comfortable standing right next to other person…”
Note that the question posed in the interview was not directly referring to using the interface with multiple people at the same time. The question allowed for such answers and gave the interesting point on personal space during interaction.

Participant 4 talked about the direct interaction with people and what might be required for using the system: “In a house it would be convenient, because you know the people who are with you in the house, so you would tell them at first how to use it and then you would know which people are using the interface…the system”
Participant 5 commented on the current state of the system, with its non-critical components: “I would trust the people. So far the [appliances] are not critical or dangerous or costly”.

Participant 7 was quite happy with having an open system, as the question states in a shared house or home: “No difference…in sharing physical devices and this virtual one. It’s just sharing with your family”

Participant 10 was initially hesitant about the idea of an open/shared system: “Things could be done unexpectedly”. They then reconsidered the impact of the visual interface:
“Yeah, that makes it much easier and applicable to shared use, because you’re always aware about what’s connected to what”.

Participant 12 wanted it such that their interface could potentially be used by other people, as long as the participant controlled the connections and settings: “If someone used my envisioned wiring as it is I would be ok.”

Interaction: hand and finger movements

Typically from following the short demonstration at the start of the study, the participants would proceed to follow the same or very similar movements; smartphone in the right hand and touching the TouchWall with the left hand, index and middle finger. There were a number of exceptions to this.

Participant 2 (right handed) held the smartphone in their left hand and moved their right hand across their body to reach the TouchWall with multiple fingers. They later alternated between the left and right hand.

Participant 3 (right handed) held the phone in their left hand and mostly interacted with the phone in the hand with the TouchWall while the right hand was in the pocket. Every so often the right hand would then be used for the TouchWall. (Fig. 11)

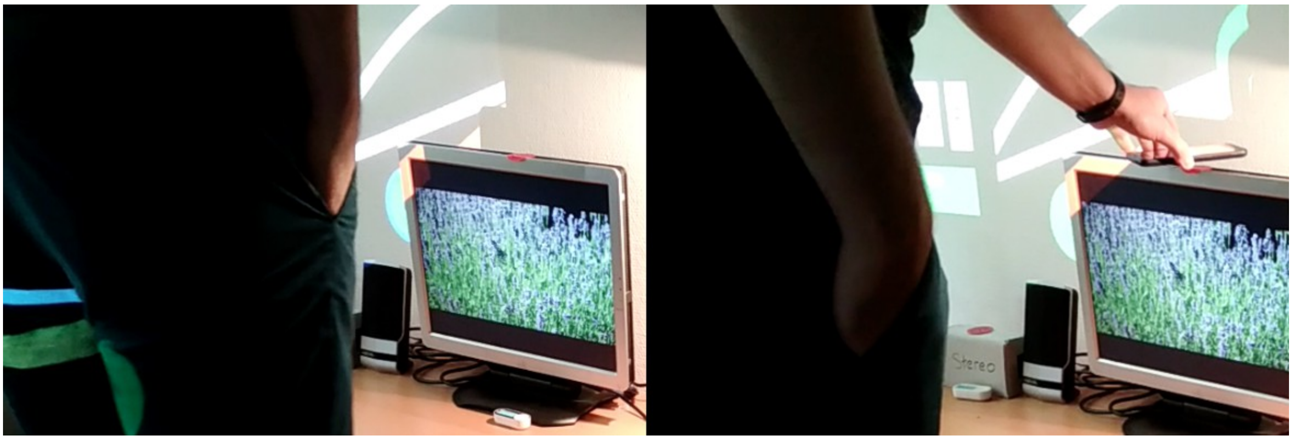


Fig. 11 – Participant with hand in their pocket. Also used right hand to reach across body towards touch interface.

Participant 8, who was somewhat unfamiliar with the NFC interaction, exaggerated their movements as they approached the devices with the smartphone. They were not sure as to the distance required for activation and would come from a wider angle until they realized it could be completed with less effort.

Participant 9 (right handed) did much the same as Participants 3 and 4, also giving reasoning why they were using their strong hand to operate the TouchWall: "Usually I do most of the work with my right hand so that's why I was [reaching over]". This indicated that the TouchWall required more work and required the primary hand.

Participant 12 clicked the touch interface with their right hand while the phone was still in the hand. (Fig. 12) With this they alternated between using their middle and index finger. Later, when they used the virtual on switch, they swapped the smartphone to their left hand to interact unhindered with the TouchWall.

Fig. 12 – Using the touch interface with the smartphone in the hand.

Participant 13 also switched to their right hand after a period of time, despite having used their right hand up to that point with the smartphone.
Some participants such as Participant 13, who had used their left hand, would noticeably rotate their hand such that they approach the virtual devices switch buttons from a right angle. The act of rotating the hand to activate the left and right buttons was quite common, with participants noticeably moving sometimes from a 'vertical' touch interaction (with two fingers pointing up) to a rotated interaction with fingers horizontal, or vice versa (Fig. 13).

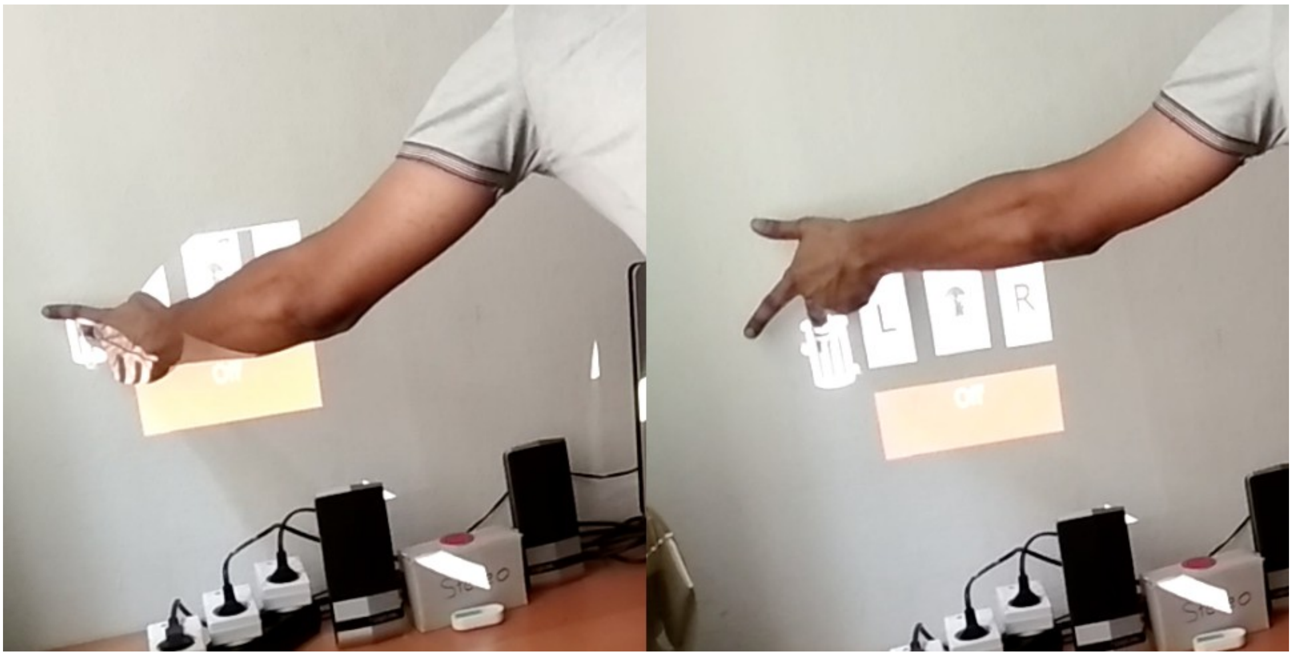


Fig. 13 – Example of rotating hands to get a second attempt

Hover effect

From using UbiDisplays, it was clear that it was not a ‘true’ touch interaction, but rather an estimation of finger placement and distance. With practice, a touch-like input would be more realizable with users. The ‘hover effect’ occurred when the participant would hesitate and hover their hand just above the TouchWall and cause the interface to activate another element of the interface. This accidental clicking is more avoidable within UbiDisplays by creating bigger elements or wider gaps between elements.

The hover effect was quickly mentioned when it occurred to Participant 11, which caused them to approach the interface differently: “Maybe because of the hover effects I have to come from above”. They then tried to avoid the other parts of the interface and used their hand to click from above. This action “top down on touch” was also observed from other participants, who were not prompted.

The hover effect sometimes also caused an unknown reaction. For example, a participant would try and click to switch the virtual devices, while unknowingly trigger the activation state of the virtual object. Then later when they tried to connect separate devices a virtual line would be created.

In one case the hover effects somewhat assisted Participant 8, as the tracking points from UbiDisplay were visible. This made it possible for the user to make a decision before committing the action with a ‘touch’ event. As such, they were able to readjust themselves to a stand at a comfortable distance.

The TouchWall

The TouchWall was quite popular amongst the participants, as to them it was a novel interaction to be able to touch a projection on a physical wall. Despite this, it was certainly not without its criticisms. Given that the TouchWall was on the left side of the interaction space, it was noticeable from the video footage that people would often lean to the left and sometimes briefly stand on one foot to reach the interface. It should be noted that a barrier was placed in the area directly in front of the Kinect so that the tracking would not be interrupted.

Participant 1 was thrown by having two modalities of interaction rather than just one: “Sometimes I didn’t consider one…because this [points to Virtual Screen] and this [points to Physical Screen] is an interface, but why should I use the other interface to disconnect the other interface?”.
They suggested overlapping the line to delete it like it was created. This would be certainly possible with the NFC interaction, but was left out due to the existing logic from the touch interface version.
“Would have made the connection again to remove it…they are kind of two different interfaces”.
“I was considering when connecting the TV and speaker that they also turn on both. They belong together…”
“It has problems to recognize the buttons”

Participant 3 simply said: “It’s cool for me to be able to cycle through the virtual appliances”.

The calibration was off very slightly for Participant 7, meaning that when they tried to touch the right button on the TouchWall they would have to move their fingers slightly to the left. They would generally try to touch the right button on its right edge, meaning that it would sometimes not activate. Despite this the participant also expressed a greater interest in the touch than NFC interaction.

Participant 9 didn’t find the ‘bin deletion’ very intuitive, commenting on the end that they would prefer to tap on the line and be able to delete it from there: “I press the line and it just disconnects”.

Participant 12 expressed their enjoyment with the touch part of the interface: “What I like is that is works…after I configured it”. [They demonstrate the touch with his right hand.] “That brings the most enjoyment”

Participant 13 also physically attempted to touch the nodes on the NFC interface, but when unsuccessful they returned to using the NFC smartphone.

The left and right buttons on the touch interface were generally accepted by the participants, with most of them only questioning if there were more than two virtual devices. A few participants still attempted to press the left button quite often, despite being aware of the hover effect that occurred. However, it did take some time for participants to realise that the image of the virtual appliance was a clickable button. Participants were initially observed trying to touch the other available buttons, in particular the virtual on/off button.

System feedback & warnings

Feedback is a very important aspect of a systems design, especially in interaction design and freshly constructed prototypes and interfaces. They let the user know that they have accomplished some action, helping build their mental construction of how the system works [34]. Most participants talked about the feedback when asked questions during the informal interview, but feedback during the study also sometimes prompted a reaction from the participant.

The speed of the feedback was sometimes an issue for users. Participant 1 said towards the end of the user study: “Maybe a hardware problem…I don’t want to wait too long for it to activate”. Participant 5 also said that: “Touch interface to the left was sometimes laggy”.

Participant 3 appreciated that the vibration function gave them knowledge of their actions: “I like… as soon as I select something I get haptic feedback”.

Participant 4 and 10 both said: “The vibration is good enough” and “vibration of the phone is nice…it lets you know something happened”, respectively.

Participant 5 commented in general about the system noting the vibration feedback in particular: "Cool…immediate connections and nice feedback. Vibration feedback worked". The visual feedback for this participant was less clear: "…[participant uses NFC and the circle changes to blue, indicating activation]…I wouldn't have known that intuitively". "Other than that I think I understood how the interface worked"
Participant 5 also considered the importance of giving system status, especially when used with other people. It would be important for users to be aware if there were any critical connections. "Maybe not to have a specific mode for secure interaction, but it's helpful to display a warning if there's something that's more costly". In some cases it might be pertinent to assign an importance to certain objects, so that additional properties of the device are made clear and not bypassed unknowingly. Participant 5 thought of a: "Delayed activation...a popup saying "Garage door is open"".

Participant 8 had a misunderstanding at the beginning where they 'activated' the device using the NFC smartphone and then tried to turn it on using the virtual 'on' button. This visual feedback eventually became clearer: "I liked the vibration feedback because that was sort of immediate and also the rings around the buttons".

Participant 9 also made a valid point about the general safety of the system. The objects in the HomeNodes system are not all powered from the exact same socket and daisy-chaining the extension leads is avoided. However, in a more complex system there is a risk of too many objects being brought together in a single space and drawing too much power from a single source. Participant 9 makes the case that the system could help in this case, provided it is fitted with the necessary electrical monitoring equipment and logical safety checks. "In a sense it's secure. With [many] plugs you might have a short circuit".

Mobile

The study and subsequent interview discussion once again brought up the topic of mobilizing the interface and making it remote.

Without being prompted or told about Reality Editor, two participants suggested using Augmented Reality.
Participant 10 imagined it might be nice to work with: "Augmented reality….the objects themselves could be glowing". "I think that's more intuitive…maybe you can do it on the way going out of the home". "would be nice to take the [Amazon Dash] button with you".
Participant 12 suggested using some kind of "Augmented reality headset", but was not sure how it would be visualized other than HomeNodes within AR. Participant 12 went on then to describe their ideal interface: "I would configure it once and not configure it again…I would prefer fast access to the buttons, maybe an application for my device where I have a set of buttons and some reasonable interface".

Participant 2 preferred having a compact remote interface that is easier accessible: “Possibility to do it remotely…I don’t want to stand up and go here and click there…”.

Participant 8 said that they: “...can also see it as a remote interface”.

Participant 11 was adamant that the need to physically go to the devices was unnecessary: “I assumed you could control everything remotely. If I need to go to the device to connect I really don’t see the point. If I have it on my smartphone I could just swipe with a line and they’re connected. If I need to go to the wall, as a lazy person I really don’t see the point.”

Other noteworthy findings

The following list of topics occurred less frequently but still presented interesting views into the perception of the system.

Continuous flow

The topic of ‘continuous flow’ was first properly noticed in the final HomeNodes system. This functionality would definitely make sense in an improved version of the system, as creation and deletion of lines would work faster. Given that there was only binary connections between devices, it would make sense to assume that one could assign a connection directly after the other. The logic in HomeNodes would of course need to be modified to allow for this.

Participant 10 even remarked that: “I expected that the connections could be continuous”.

Participants 2, 7 and 8 all were observed trying to accomplish the same action.

Colours

The colours of the connecting lines were arbitrarily assigned and were there to distinguish individual connections between a set of physical devices. This confused some people and had to be explained more at the end of the study, including Participant 10, who said: “I was also a little confused by the colour coding…maybe the colours should mean something…for the mapping maybe also some arrows…I thought that there was some additional information”.
This aspect of adding arrows is interesting, as it resembles the direction of Reality Editor and also a suggestion from the paper prototyping about primary and secondary devices.

Participants 3 and 4 wanted to know if there was a significance in colour with Participant 4 saying: “Does the colour of the lines say anything?”

Participant 13 had to enquire about what the green colour meant between nodes and lines, meaning that there was some confusion as to how the green node (on) was different to the green line connecting the radio to the speaker.

Changes to visual layout

Changing the layout were recommendations made by the participants as to how they might want to see the interface. This mainly came under “interface above object” and “labelling”.

Participants 4, 6 and 7 expressed an interest in having the interface above the objects that are not mapped to the objects themselves and show a more abstract but clear connection between device nodes and object. They gave suggestions on including pictures or icons with the interface to differentiate the objects. Participant 7 thought that having the existing system for the physical object would be nice, but an alternative visualization of objects in other rooms may be nicer to see above the other physical objects.
“Would be cooler if it was above the stuff”, “Two points and having them labelled”. (Participant 7)
Participant 7 talked about the effort required to move across and between rooms by touching the devices manually:
“You can combine all the things and provide the choice...It’s fine when the physical devices are placed together...but if I want to operate something at the same time in this room and the other room I have to go here [mimes interaction] then move to the other room.”
Participant 7 continued then to describe having the system in a singular place as HomeNodes does, where it might control multiple rooms from a single place.

Participant 6 was confused somewhat by the virtual connection lines. They said that the “line originating from the off button” made it less clear that it was connected to the virtual household appliances. The participant thought it was just an alternate control for the connected physical devices. The reason for the line connecting to the on/off button in this case was the setup of UbiDisplays, where the Virtual Screen was accidentally placed slightly higher. Despite this, it showed an interesting aspect and the importance of line origin and ending in showing the purpose of a displayed interface and system function.

Having the interface above the objects meant it was at a more comfortable operating position, without having to bend down. Participant 6 and 7 both said that this aspect would mean that smaller children would find it more difficult to use the interface, like putting something on a shelf to prevent them reaching it.

Participant 9 could understand the lines and nodes, but was unclear what one of the appliances was just via the picture (dishwasher).
Participant 9: [Confused what the dishwasher was] “My fridge is exactly like that!”

Participant 11 wondered: “Why is the delete button in the corner? Why not in the center?”. This was again due to the previous build of the HomeNodes system which used touch only. Accidental presses of the delete button by having it in the middle was a high likelihood. An NFC tag could also have been placed on the wall for the sake of the prototype system, but was not chosen given that the TouchWall was a working alternative.

Naturalness and consistency

The touch and NFC interactions chosen for HomeNodes were seen as a way of bringing the physical interaction back into the control of household objects. Advanced technologies, like tablet PCs, desktops and dashboards, certainly allow for one to efficiently control the connecting of these devices in relative comfort. In modern society, smart devices and touch screens have become an almost ‘natural’ way of interaction [22]. Some of the participants, despite being able to operate HomeNodes, were less convinced on the practicality and naturalness of the system.

Participant 5 had some back problems, so this made it difficult for them to bend down to use the system. They therefore had to try and use the system while in a crouched position, making it sometimes awkward to reach the interface elements.

Participant 8 was thrown by the overall system and wasn’t initially clear on the system’s operability and practicality: “I didn’t really understand it. It’s not very intuitive”.

Participant 10 raises some practical issues with setting up such a system within a home. If the device’s entire surface was able to be activated then the natural ‘tap’ interaction could be preserved. However, some devices may be placed in varied positions and not directly or easily accessible: “maybe it might help if there were dedicated icons…could be some interference between close devices…as long as it’s reachable…the most accessible part”.
Devices that are also close together would need a slight modification in the visual interface, such that the nodes are smaller or connecting lines are curved. Like Bluetooth or NFC, both technologies have a particular symbol assigned to them (Fig. 14). Objects included in the HomeNodes system might benefit from having dedicated symbols showing that the interaction is available.

Fig. 14 – Objects with activation symbols (like logos) for Bluetooth (left) and NFC (middle) which indicate a standardized technology. The target right was used in HomeNodes with the NFC tag underneath and not using the trademarked logo. The tags themselves do not have the trademark.

Participant 12 simply stated: “It’s possible but that maybe not a natural way for me to do it”.

Participant 13 didn’t like the wide difference in interaction modalities. Projections exist on the entire surface, so it is inconsistent to see that one part of the wall is not touch-enabled: “After one try I realised how to work with [Virtual Screen]”. “The [Two modalities] are inconsistent….as a user it’s a bit complicated”.

Learning and Teaching

In Interaction Design and Development one would hope that, in most regular consumer cases, your design can be used ‘out of the box’ with as little introduction as possible. In the earlier prototyping and design phases, this shouldn’t be immediately expected. Hence, the reasoning for completing user studies, user-centered and cooperative design, as well as other interaction design processes. During the studies, the participants also confirmed the necessity for some sort of teaching or trial and error to build an understanding of a ‘new’ technology.

Participant 4 talked about passing on the knowledge: “...so you would tell them at first how to use it and then you would know which people are using the interface…the system”.

Participant 9 admits after using HomeNodes it would take some time to master: “It would take some time to get used to it. As a person you would repeat the things and then start to remember.” Later they expanded on this: “I think it would need some education for the person at home”. “It’s a technology, so you have to learn the things…maybe some basic steps, initial knowledge and then it will be used, and quite easy.” “Initially for me for one minute or two minutes I couldn’t see what actually I am doing… but now it just looks familiar”.

Security

When queried about the use of the device with multiple people in a house, most participants were open about using it, as it showed all they needed to know and what other people would need to know. This was more in-depth with certain participants who were quite content with showing the visual connections, but that the configuration should have its limitations for unwanted users.

Participant 1 included a condition that: “Maybe I would feel safe when it’s only possible with my smartphone or fingerprint pressing”. “I don’t want other people to mess around with my connection”.

Participant 6 brought up the case where shared devices are at risk from accidental or unwanted usage. They would have: “Security settings for shared devices…a private printer that you can show off but you can have security settings for your own devices, no one [who] can turn it off on the shared projection”.

Participant 12 said that: “I would not want people to touch my wirings”. “If someone used my envisioned wiring as it is I would be ok. I would want some sort of authentication or some sort of right to block someone from [changing it]”.

7. Discussion

Home automation already carries an inherently interesting interpersonal aspect. Outside of the cases where RF remotes were used within houses over the last decades to control devices ‘between’ rooms, home appliances are controlled in the same room where they are located. Home automation means that there doesn’t need to be anybody in the room for certain appliances to change their properties or complete a task. Devices can practically invisibly run their course on a timer or modify their settings with the notification of changing weather patterns. Rooms can in a sense become ‘ubiquitous machines’, changing their parts to complete an objective. Should the context of the room change significantly, we should also consider those who are the end users. Every person has some kind of goal when they enter a room, such as reading a newspaper or sleeping. However these goals might simply not align with other people, and with the advance of home automation, this may become disruptive. This also applies to HomeNodes, which while giving people the opportunity to understand a connected environment, may leave external parties oblivious to the outside connections. This sentiment is echoed by participants during the users studies, who wish for a clear way of identifying what the status of each room is and what objects or appliance lie within. Warnings and safety are also very important considerations, with the highest priority being people’s safety and the ability to comprehend and visualize (both visually and mentally) the results of the system’s functions. People, like Participant 7, question how intrusive a wall-based IoT system can be, even across a single room, taking the effort to get up and move. The design and perception of the room could arguably change when there are pipe-like lines stretching along multiple surfaces of a room. Projection mapping, particularly in the artistic sense, is there to give the illusion that the surface is moving, malleable or non-static [9]. The Virtual Screens of HomeNodes could potentially have multiple iterations in a single room. In an expanded HomeNodes system with projection mapping, one question is: would the abstraction of the virtual objects overlap in a single room or return to the confusion of unidentifiable home automation object identities? Would the illusion of projection mapping detract from the objects themselves or the objects in the surroundings?

The authors of UbiDisplays note the importance of colour when displaying an interface. This has been particularly true with HomeNodes, which relied on colour to convey the system status. The colours confused users, with some questioning if the line connections had any meaning. Therefore colour in an IoT interface has a noticeable perceptible quality that generally is assigned some meaning. Good interfaces should also work decently without colour, given that certain people see colours differently or not at all. Colour was also mentioned for the imagined systems in the low-fidelity prototyping session, where participants included different coloured nodes, rather than lines and physical LEDs with different colours that represented a certain function and connection channel. Shapes and context were explored in this thesis, with users sometimes moving and bending to interact with home devices in a new fashion. This point is not in regard to the projection occlusion which obviously presented its own challenges for users who had to move out of the way to see the interface. Rather, the HomeNodes system gave the opportunity for users to experience the room and how devices can connect to each other outside of a smaller screen. While not always fully interpreted or conceptually understood correctly by the user, participants at least understood the base purpose of the system and how devices connected by the end of the studies. The techniques used to associate devices as per Chong et al. [8] were included in the development of HomeNodes:

1. Guidance: The nodes and targets next to the devices indicated some interaction was possible. The creation of the lines established the relationship between the devices.
2. Input: Touch and tapping are given as input methods to activate one of the connected nodes.
3. Enrolment: The identification is the device itself, with all devices in the system having the same importance level and similar functionality
4. Matching: The interface and objects are all visible to the user, so they are aware of the last object they have activated, being able to confirm the secondary connection, stop interacting, or later delete a connection.

The objects themselves may also need to have restrictions or specialized inputs and outputs for the HomeNodes system. Participant 1 for the main study was not sure about why one might connect a lamp to a stereo, rather that the stereo should be available to the television. These "pre-conceived notions" play a large role in the user's acceptance of the interface and whether its purpose is meaningful to them. The low-fidelity study showed people trying to double click on certain interface elements to activate them. This shows either that the desktop metaphors are still prevalent in other interfaces or that there is a certain urgency behind making sure that the interaction goes through in this new and unknown interface. Participant 8 also showed large movements initially, indicating the need for larger movements for the unfamiliar interaction.

In contrast to the paper by Lee et al. [24], the participants in this study were more inclined to also use their non-dominant hand instead of just their dominant hand. This suggests a willingness to use the entire body when interacting physically with the two modalities. A few participants also said that they would prefer to sit on the couch and control it from there. This then may lead them to return to a usual interaction method where they use a touch device with their dominant hand. Another important consideration is that HomeNodes operates mainly through taps or presses, meaning that the participants didn't often have to hold their hand out for a long period of time. The exceptions occur when the system didn't respond as quickly as expected and the user would have to try tapping again (TouchWall) or for a longer period of time (NFC). Other more complex touch interactions such as dragging, sliding or flicking would require slightly more time and may lead to even more fatigue. The physical effort required for gesture or physical interactions was noted in the research and a frequent concern from the user studies, often as a result of the projection occlusion. The use of the TouchWall caused some participants to hold their hands in different ways, where they were unsure which hand orientation would best work with it. This is very much in contrast to regular touch screens and buttons, which normally only require one hand orientation to function. Participants who used their fingers from the top down were essentially using the minimal space they could to ‘interfere with’ or activate the touch interface. Interacting from bottom up or with multiple fingers often introduced extra point recognition from UbiDisplays.

Projection mapping is not needed in direct displays of information. There are already numerous other options of displaying a home automation system, with OpenHAB and Reality Editor. Displaying the system near the objects was also suggested by study participants, as one can directly see a correspondence, provided the amount of objects is reasonable. As long as the objects are labelled correctly and represent the object sufficiently, users could make sense of it in a similar fashion midway between HomeNodes and typical home automation software.

An important consideration for this project and the user studies is that those who tested the system were quite young and could move with relative ease. However, with an example like Participant 5 who had back issues, it is clear that HomeNodes would not be ready for the elderly. Making the system as visual as possible and modifying the timer based functionality would be necessary. Young people would most likely be able to use the system as it is, but improvements are needed so that fast reaction times are not required. The user simply sometimes wishes to be lazy, with convenience and speed often outweighing the novel interaction of physically interacting with the devices. The low-fidelity prototyping session showed that having this remote control interface is desired.

The vibration feedback was helpful for the NFC interaction. Vibration is quite important for other NFC related tasks in daily life such as contactless payment [29]. A vibration (or sound) is helpful in these cases, as the user is not always in a position where they can see the smartphone screen. This was a similar case with the HomeNodes system, where users would often block the interface by standing in front of the projector. They were content with the fact that they were receiving at least some confirmation that their action had effected the system in some way, learning eventually that one only really needed the vibration when setting up the connections. While the system did give other feedback in terms of the blue rings around the nodes, this was not always visible. Therefore, having the fallback of the vibration proved useful. This potentially constitutes a good practice when creating a largely physical interface – one should provide at least one form of feedback for the user where necessary. The interface should be tested such that if feedback becomes unnoticed or invisible, an alternative approach should be considered. The in-built feature of visible finger points with UbiDisplays was a benefit for this study, as it offered additional feedback where direct and exact haptic touching was unequal. Participant 8 of the main study approached the system slightly differently and with a bit more comfort when they realized that there was this visual feedback. This indicates that with a lack of haptic feedback additional interfaces tracking elements would be beneficial, as in the Overlay system by Satyanarayan et al. [36].

Commenting on the connections and the understanding perceived by Participant 9 and 12, one could think of how, with the ability to now connect devices in a system, the individual devices now somewhat combine into a singularity. Thus the devices or home appliances might not be unique objects that one can buy and interact with singularly, but instead a part of a collective interactive space. The HomeNodes system can be potentially blurring this line, in contrast to the regular home automation system, which is clearly its own interactive space with control over multiple devices. It was found during the user studies that some participants were quite aware of how the lines might be effected by surrounding objects, with the participants demonstrating the two-pointed line in the low-fidelity prototype and then later commenting on the intersections with the physical objects. There is a certain cognitive precedent apparent with some users, who talked about having to 'map' the projection and objects together to get an overall understanding. The HomeNodes system makes use of 'projection mapping' and proximity to build this cognitive or mental model of the objects and their states, something that takes longer for others to build.

One could also draw parallels to the phenomenon known as the 'island of things/control' as described in the paper by Blackstock and Lea [7] where, despite having a new interaction method in a home, the selection of devices stands by itself and doesn't feel 'connected' to other areas of the home. Currently HomeNodes could run into a scenario where one physical object in a room controls multiple virtual objects in other spaces of the house. This could theoretically lead to a very cluttered interface where multiple lines span across a single surface. The scalability must be considered here again, where it may be simpler and more comprehensible to visualize the household as a series of organized nodes with identifiers. In this case the interface can again be projected as a display and comprehended by all those in the room and neighbouring rooms. Like as in the Overlay system [36], making the user focus on a smaller part of the large interface may help. Despite there being few projected display elements, Participant 8 and Participant 11 felt 'overwhelmed' in some shape or form. This is then a matter of making an intelligent display that is not overly intrusive to other members of the household. One could think of the experiments conducted by Lemmelä et al. [25], applying context-awareness to HomeNodes. Portions of the HomeNodes could fade in and out according the required need and viewing position. The user could potentially be in a context or state such that they can modify just a portion of their connected system. To then get an overview of the system, the user could step away from a wall to view the connections leading in and out of the room. The Overlay system becomes more applicable when one considers using HomeNodes as a multi-user system. Whether this assumption is true remains to be seen, and would need empirical evidence about the comprehension of alternative home automation visualizations. At this point where multiple objects are being connected and disconnected in the house, it might be wise to have a combined system, in which HomeNodes is just a visible interaction method.

7.1 Future recommendations

The positioning of the objects and the interface were hard-coded into the HomeNodes system to avoid extraneous bugs and issues with interaction. However, some users wished for the further customizability of a system, where they can control the node and line positioning, have their own settings and take the interface with them on the go. This customizability is especially true with the touch interface, with participants wishing for some way to move the 'delete' icon or virtual room selection node to a different part of the screen.

The demographics of this project mainly belonged to those in the computer science field. The users were young and showed enthusiasm and engagement with the technology. They were able to give suggestions about technological improvements and compare the system to the multiple technologies with which they have worked. They also came with certain expectations that might be homogenous with students and the technical workforce. Therefore, it would be beneficial to conduct studies with regular consumers and people who work and live in different circumstances. The use cases for HomeNodes can be wide and reaching, with applications for the elderly and families at home who want to be more efficient and aware of their home appliances. This, in turn, comes with the requirements of modifying the HomeNodes system in accordance with User Centered Design principles.

Like the previous point, the ability to customize the positioning of the nodes might also include the ability to scroll through or pick and choose the external home appliances. A number of people found during the evaluation that being able to connect a continuous line without stopping would be advantageous. This would fit particularly well with line-drawing and sketching with the users hand on or near the touch interface. As an additional improvement, it might be beneficial to provide the user with additional haptic feedback as they use the touch interface. This is especially true with UbiDisplays, because touching such a projection wall is not directly comparable to a capacitive or resistive touch screen. The feedback might occur when the interface changes, but due to the hover effect this is slightly different. Certain Android devices come with a setting that allows for interfaces elements or the keyboard to vibrate the device. This acts as a confirmation of an action [45], which may or may not benefit the TouchWall. In this vein, one could also think of the applications for the visually impaired, to whom half of the current HomeNodes doesn't directly apply. Assistive technologies such as voice output or micro-braille actuators [49] are all valid ways of communicating the necessary information.

Should this project or idea be taken further and reliably established it would be quite interesting to find out if the same standards for smart devices translate to the embedded digital interaction explored in this thesis. Design practices such as a 'grid design' and 'responsive development' all exist because their interaction exists within a rectangular and enclosed display. Tried and tested design ideas such as the raised or embossed button have competed against modern 'flat' design as interactive user interface elements [11]. Visually embedding interfaces on or near interactive devices opens up the shaping possibilities when designing interfaces, in particular with projections and the possibilities of projection mapping. Embedded interfaces are already in development through the use of Augmented Reality or projection, giving workers the ability to see more information about the system. The topic "Learning and Teaching" outlined in the findings was mainly about the use of HomeNodes with other people. HomeNodes itself, as shown by Akiyama et al. [1], could potentially then be used for educational purposes or as a way of showing more details about a system. This could especially be useful in an IoT system, where network configuration and debugging is needed. HomeNodes could also adhere more to Nielsen's 10 Usability Heuristics [46], as they have been proven as being good guidelines for interaction design, particularly in web development and design.

From a coding perspective the interconnected logic within "divconnect.js" could potentially be shortened and reorganized to allow for quicker response times and website page load speed. Numerous 'if' statements are used, but an alternative to this would be the use of 'switch/case', whereby the program runs logic when it finds a fitting state to run. Some experimentation was also done with Node-RED, which is widely known as a versatile IoT ‘mashup’ system that works well within web development. Therefore it may be another streamlined alternative to the current HomeNodes system with fewer intermediary components.

Should the system be available on multiple devices, it would make sense to explore how one could transition from desktop to tablet and then to mobile and vice versa. A good inspiration or basis of this could be the Reality Editor application, as this also presents a nodular view of the objects you have connected. Mobile responsiveness needs to be considered if the system can become mobile, potentially with the help of a nano or portable projector. The system can also become even more ubiquitous to the environment, although this may require the environment to be specially built to hide the necessary equipment such as the projector, the communications devices (Arduinos or other wireless signal components), the processing computer and potentially specially built or designed household appliances. Having the technology ‘hidden’ depends on the user’s preferences. There are those who are interested in technology and hacking who may want to use multiple Arduinos or microcontrollers to adjust the volume of their speaker or dim their lights. These electronic toolkits, as seen from a simple implementation with on and off, would suit HomeNodes. The Breakout library can be used for more intricate and incremental controlling, which would likely bolster the usability of HomeNodes in home scenarios.

The method of communicating via NFC on Android required the purchase of multiple different NFC tags in order for each tag to have a specific identifier. The Sensors2OSC application code is open-source, so it might be possible to include code that can read a programmable identifier from the NFC tag. One option for deleting the connections (aside from clicking or reselecting the lines) would be placing a fifth NFC tag on the wall. The user could then potentially move this tag, as it is not assigned to a single physical place or large household appliance. However in this project, the NFC tags are an early example of how the objects could be identified with electronic chips. Being able to move the bin icon in the interface to a wished position would prove a much more versatile solution.

From a technical standpoint, technologies other than a low projection could potentially be used to display the interface. Examples of large interactive displays could be large electronic touch screen displays, rear mounted projector or a short range projector. The most obvious recommendation, should the room support it, is a mounted projector that can reach the vicinity of the household objects. This could be placed high and parallel to the nearby surface, causing smaller shadows than a lower projection. Another alternative is a short-throw projector mounted perpendicularly to the wall such that the projection lens projects on the required wall. If not already built-in, the skew of the projection would need to be modified either with projector settings or within the displayed interface itself. Building a fully crafted laboratory testing room with customized portable walls could also be possible. This would give the creator the full freedom to construct their own interactive walls, for example by projecting from behind and using specialized material such as electronic wallpaper or paint. It would also require testing to check what shadows would occur should there be objects in front of the beam. By having an alternative accurate display, it would intricately effect the design of the connecting interface. UbiDisplays recommends having large, widely spaced elements. This may make the interface usable and functional in the end, but may retract from the aesthetics of what was earlier envisioned.

The downside of using the Amazon Dash buttons in conjunction with openHab is the slight delay from button-press to output. This is primarily due to the unconventional way of repurposing the device. Therefore, a suggestion might be to make use of ESP8266 wireless or wired buttons that allow for quicker response time. The buttons would then also ideally be as ubiquitous to the connected appliance as possible, or else the inherit physical conceptual model of the device may be lost or skewed, like with a home automation interface. There are two different Arduinos used for the HomeNodes system. One recommendation would be to try and combine the libraries used for Breakout with the Radio Frequency sketch, so that only one Arduino is required. This would also help overcome the issue of having a limited amount of input and output ports on the Arduinos.

With the exception of the projector, the costs associated with recreating the HomeNodes system is quite reasonable. As shown from the cost estimation found in the Appendix (Price table), the system (without projector) can be built for around €100. The projector price can vary widely, but even a cheap miniature or larger projector should be able to display the simple interface. The projector should be at least able to adjust its focus and have a large enough projection space that it is able to reach the devices. While the costs for constructing the HomeNodes system were reasonable, they also were a limiting factor of what was achievable in this project. More sophisticated and expensive home automation systems could be utilised to make HomeNodes a more integrated and recognizable tool for reconfiguring home appliances and applying logic eg. Reality Editor.

During the evaluation phase the participants were asked about their worries about security and sharing the HomeNodes system with other people in a shared environment. Their comments ranged from acceptance of usage from other people in the home to personalized protected interfaces. Should the devices be open, one participant at least hoped that costly or dangerous devices could be at least managed such that nothing really accidental or detrimental could happen to their home or appliances. One participant was concerned about personal space. There have been a number of studies done on proxemics, with the initial research pioneered by Edward Hall [15] [27]. The behaviour of people depend on the distance between each other, also then effecting the interaction. In addition to the participant’s comments one can also consider the vulnerabilities existing in the network and the programmed code. HomeNodes does not explicitly require password protection, although in order to use the current implementation with Amazon Dash buttons, a WiFi network is used. These networks can be password protected and the Amazon Dash buttons verified through the Amazon smartphone application. Like other WiFi enabled devices, it doesn’t need to be reconfigured unless the WiFi password is changed. However, as of October 2017, a vulnerability was discovered with WPA2 enabled devices called ‘KRACK’ that allows for information to be intercepted [14]. Researchers have said that provided one of the end devices has been patched, the risks would be minimized. Despite this, there may be situations where IoT devices may still communicate unprotected information. This includes the Amazon Dash button, which, being a standalone device, will not likely see updates. Therefore, those who wish to work within the IoT field should now take extra security precautions, especially if sensitive data is involved.

For evaluating the system a more extensive mixed-methods or even quantitative focused approach could be used. The user experience of the IoT system can even be quantitatively measured using the User Experience Questionnaire [38] or the AttrakDiff questionnaire [17]. The quantitative approach in this case would of course require some significant discussion and contemplation to elicit the research questions and what should be measured (besides user experience). The tests could return to lab-based scenarios where the system setup may be modifiable, allowing for different versions of the system to be tested in A/B tests. To explore the cognitive benefits of having a visually displayed IoT interface one could conduct a test such as one by Tan et al. in their paper "The Infocockpit: Providing Location and Place to Aid Human Memory" [41]. Here it was found that adding an ambient display in addition to regular monitor displays helped the user remember semantic information, such as word-pairs. This aspect of the HomeNodes system could be measured over time to see how well the recollection compares to a typical home automation system or Reality Editor. To evaluate changes in context observation before participatory design would be useful in the evaluation of an IoT system across multiple rooms and environments.

8. Conclusion

It was evident from the evaluation that an interactive Internet of Things system benefits from cooperative design exploration and observation. Household objects are used everyday in people's homes. The Internet of Things development realm should not seek to change a device beyond recognition or prevent the user from completing their expected tasks. There is a danger in the Internet of Things of complicating already quite user-friendly objects. Making them 'smarter' does not necessarily lead to a better human-machine interaction. Adding an interaction that is unfamiliar to users may alienate the user even further, so designers should strive toward keeping the affordances intact where possible. Having the ability to accomplish more, just by 'flicking a switch' could offer a greater efficiency and usefulness to otherwise bland household appliances. These new recognizable interactions and smart solutions may surprise the end users, as well as their developers.

HomeNodes could be used in a large room installation, crossing multiple surfaces. However, from talking with users who had used the system first hand, giving people the option to modify the system or view it in an alternate display would be beneficial. In a fully-realized or commercial interactive IoT or home automation system other interaction methods could be realized, such as motion, gesture recognition and voice input. These inherently would have more intricate controls and functions required. Algorithms and mathematical transformations would quite likely be needed to further explore the realm of direct visual IoT interaction.

The participants who gave positive feedback during the users studies would try multiple things and wouldn't pause very long while using the system. Participant 4 very much confirmed one of the aims of HomeNodes during the final user study, commenting on its practicality without having to act through an 'abstracted' touch screen. This example, and the others during the studies, shows that HomeNodes can widen the possibilities of including additional interfaces that support physical IoT interaction. At the very least, if the system is not used for a critical or serious purpose, it can at least be used as a ‘playful’ way of connecting objects. Making the system fun to use plays a big impact on the user experience of an interaction [26][30]. This relatively cheap HomeNodes ‘home automation’ system could then inspire users to come up with creative combinations and ideas.

This project aimed to illuminate the possibilities of interaction design in the physical Internet of Things realm. It is hoped that the topics discovered during both the low-fidelity user prototyping session and final system study can inform the IoT field on building physical IoT interfaces. The results, discussions and suggestions from this paper may help future Interaction Designers to reflect on critical design decisions during and after development.

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Appendix

A.1 – Interview Questions (Low-Fidelity User Study)

Pre-questions

1. Do you currently use smart controls for appliances in your home?

a. If yes, how long have you been using them?

2. Have you ever repurposed an appliance to work in a way that was unintended?

Open Low-Fidelity prototype

3. With the help of the material supplied, explain how you might connect two different devices to each other.

a. What do you think of using your hands to connect devices?

4. What did you think of your own interface? Is there something not at all realisable with the materials provided?

Touch Wall Low-Fidelity prototype

5. With the help of the material supplied and the current display, connect two devices to each other.

6. What worked well? What were the challenges?

NFC Wall Low-Fidelity prototype

7. With the help of the material supplied, the current display and this mobile device, connect two devices to each other.

8. What worked well? What were the challenges?

Review

9. From the three interfaces used, which was your favourite? Explain

A.2 – Interview Questions (Main Study)

1. What did you think of the system? What were your first impressions?

2. How do you find the relationship between the physical devices and the visual interface?

3. Were you satisfied with the feedback you were receiving?

4. How would you use the system in your own home?

5. How would you feel about using your created system with other people?

A.3 – Analysis of Low-Fidelity prototyping sessions

	Patterns/Themes	PAPER PROTOTYPE SESSION
		Participant 1 (F)
7	Mobile	Projected and on tablet interface.
3	Pre-configure	Setup the logic beforehand and how you want to activate the connected logic
2	Rooms	When setting up you have the option of setting the rooms and the objects inside of them
1	Warning	Everything shouldn't turn on and start playing at the same time
6	Touch	"Using hands"- very common [touch screen]- something that people are familiar with it.
3	Physical status indicator	LED to indicate the status of the devices
5 1	Additional buttons Segregated nodes	"What worked well/challenging?" Each end of the connection could have a on/off switch, so that despite having multiple devices connected, only one side of the 'graph' activates
		(Mark) Should mention that washing machine is pre-loaded
4	End point delete	"Deleting a line" pulling from an end point.
	Extra smartphone interaction	*Tapped the phone to turn on the lamp*
 1	End point delete Mid point delete	"Deleting with NFC" UI element in the middle of the line. Going to one end of the line
6	NFC preference	NFC makes more sense. Already people are using smartphones at home.
		Participant 2 (M)
	Mobile (existing)	Raspberry Pi + phone control
	Touch	Physical touch from one to the other
	Additional buttons	Nodes along sides that change colour
3	Orthogonal	Orthogonal lines (with controls)
	Non-sensical connection	Not sure why TV connected with washing machine
	Touch (drag)	Would be ok with dragging finger on the wall
	Pre-configure	Confused by connecting and then turning on device immediately – not expected

	Pre-configure	Connection should be used for next on/off action
		Participant 3 (M) & 4 (F)
3	(Remote)	(P4.) Remote for extractor in kitchen & TV & games console - 1 year+
1	Automation	Smart inputs that recognise the incoming signals
2	Device hierarchy	Primary and secondary devices - each is labeled accordingly such that when the primary is turned on the secondaries also turn on.
5	Gesture + sound	Points to devices and snaps fingers as extra interaction
3	Proximity, Mobile	Proximity smartphone interface - radio station
	Gesture	Disconnecting from a distance
		(Mark) Wii remote on couch
	Mobile + NFC	With the NFC smartphone press a button on the smartphone interface. Starts the first one that is connected
	NFC preference	NFC was favourite
	Visible connection points/indicators	(P4.) Bluetooth icons/indicators on/near devices
	Proximity, Mobile	Proximity. Selecting on mobile interface.
	Double handed	Used two hands to establish the line connection
1	Overlapping lines	Difficulties when lines are close, on the same vertical or horizontal plane. Not a straight-line any more
	(Specific) Gestures	The cutting of the lines could also have additional features within (a certain gesture might turn off one of the devices.)
	Mobile (NFC)	‘Touch Point’ that would allow for the interaction space to appear as miniature on the smartphone
1	Continuous flow	Showed a continuous flow from one devices to another 2+
		NFC wasn’t so popular, as it required effort.
1	Personal solution	Personal solution was the favourite
		Participant 6 (M)
	(Remote)	Radio adapter for lights
	Device hierarchy	Also kind of the primary (entry point). Drawing the line.
	Orthogonal	Didn’t like the idea of the objects blocking the

		visual line connection
	(Remote) Additional buttons Rooms	Have a list of devices and the room where it is located. Would also like to use a remote or avoid having to walk all the way to the device
	Touch, Gestures (slice)	Slice to delete or selecting the line and getting options
X, 3	Touch (drag), Double tap	Initially wants to try drawing a line. Double tap to turn on the TV
	Mobile (NFC)	NFC is established, an interface could appear on the phone
	Touch + NFC preference	Would like to have the option for more than one interaction
		Participant 7 (M)
		Explains concept of misusing object - objects as a new interface method
	Additional buttons (physical)	*Explains interesting concept of having a dedicated button that can both turn the device on and establish a connection channel to another device when the same thing is done on the other device*
	Physical status indicator	*Uses LED/lights to colour code the channels*
	End point	*For removing a connection they suggested touching/holding/covering one of the buttons/indicators*
	Orthogonal	*Did a three point connection for the touch interaction*
1	State change deletion	*Disconnection- a certain state of the machine will break the connection eg. opening the washing machine door*
	Double/multi-tap End point	*Disconnection- tapping one end multiple times*
	Double tap	*Demonstrates with smartphone a double tap. From PC?*
	Gesture Partial proximity disconnection	*Holding the phone a certain way or interacting with a certain part of the device would indicate a connect or disconnect* (Up or down)
		(Mark) not just a single node, but also multiple functional buttons

A.4 – Results/Analysis Main Study

	Patterns/Themes	FINAL EVALUATION
		Participant 10 (F)
		Projector is always visible?
12	Blocking interface	*Getting out of the way of the projector * 3:26
		Could stand in front of projector and operate touch screen
2	Multi-finger	Touch screen interaction was flat fingered *from notes*
7	Hover effect	Keeps hand near screen after click, causes system to switch to another v.device
		TV didn't turn on with Dash
3	Timer confusion	*Giving reason for having time based*
6	Positive feedback	"Your setup is so cool!" 7:40
5	Continuous flow	Continuous follow-through connection 7:55
2	NFC troubles	NFC sensor sometimes took time to find 8:15
		INTERVIEW
12	Positive feedback Connection understanding	"Nice how the connection between the different devices works" * 12:40
	Continuous flow	"I expected that the connected could be continuous"
4	Colours Direction of line flow	"I was also a little confused by the colour coding"…"maybe the colours should mean something…for the mapping maybe also some arrows"…"I thought that there was some additional information"
6	Feedback (vib)	"vibration of the phone is nice…it lets you know something happened"
1 1 1	Visible connection points Proximity issues Accessible	"maybe it might help if there were dedicated icons…". "could be some interference between close devices…as long as it's reachable…the most accessible part".
9	Good shared	"things could be done unexpectedly". "Yeah, that makes it much easier and applicable to shared use, because you're always aware about what's

		connected to what”.
		(Mark) Three different rooms. How to visually identify the different rooms and who might be affected by it.
		(Mark) Using a Remote Desktop to control the interface a possibility
2 3	Rooms Additional buttons	“May also be helpful to have a little preview panel as well that shows rough…focus and context, like an additional map or so.”
2	Mobile (AR)	“Augmented reality….the objects themselves could be glowing”. “I think that’s more intuitive…maybe you can do it on the way going out of the home”. “would be nice to take the [Amazon Dash button with you”.
		<u>Participant 4 (M)</u>
	Blocking interface Connection understanding Feedback (vib) Colours	“That is one flaw…it would be better if there was no obstruction”. “That’s cool, to save time if you want to connect [and control] all devices with one device”. “The vibration is good enough”. Does the colour of the lines say anything?”
X/10	Timer/deletion confusion	*Tried to directly delete the devices after a long time*
	Timer/deletion confusion	*Multiple attempts required to delete line*
6 5	Two finger lean	*Leaning on one foot to touch with two fingers* 7:40
1	Scrolling	*trying to scroll on the interface with 1-2 fingers* 9:50
	Physical/connection understanding	“Its better if you want fast interaction with world around you, if you don’t want to use a screen all the time. It’s kind of a cool way to connect the devices without having to enter any commands or having to deal with a touch screen.”
	Blocking interface Feedback (vib) No smartphone (NFC)	“Obstruction…unless you had the vibration, you wouldn’t know at all if they are connected. It would be better if I had a projector on me maybe.” “Would be nice to turn them on [activate them] without a smartphone”
4 6	Interface above objects Labelling Deletion (non responsive)	“Would it be better if the projection was a little bit higher?” “If you hadn’t said to click between devices [I wouldn’t have known]…the name of the devices would be helpful” “Deletion…if you didn’t tell me I would think it was not

		responding”.
		(Mark) speed not great for those elderly people. Wider scale physical interaction
3	Good shared use Learning	“In a house it would be convenient, because you know the people who are with you in the house, so you would tell them at first how to use it and then you would know which people are using the interface…the system”
		<u>Participant 12 (M)</u>
	Positive feedback	“Oh…amazing!” 4:41
9, 2	Right hand, middle fingers Deletion confusion	*Went to delete the connections with right middle finger before selecting the connection”
	Colours	“What does green mean?” 6:37
	NFC troubles	*Some trouble tapping on the lamp* 8:10
	Right hand	*Uses right hand index finger* 8:33
6	Top down on touch	*Came from the top trying to avoid blocking* 9:48, 10:45
4	Unnatural	“it’s possible but that maybe not a natural way for me to do it”
3	Alternate visuals (alt)	“lacks the visualisation…it would help if they were stacked”
3	Two modalities confusion	“First impression…why are there two options?”
X, 1	Connection understanding, target ID (wall + device)	“I first have to identify this target and then I identify the corresponding target on the wall” “They are close in this case so it is easy”
	Mobile (AR), headset	“Augmented reality headset”
	Additional buttons (physical)	“Sometimes I would want to use a cord extender…I could flick a switch and everything would go on”
3 7	Pre-configure Touch (this case)	“What I like is that is works…after I configured it” *Demonstrates the touch control with right hand* “That brings the most enjoyment”
6	Pre-configure Mobile	“I would configure it once and not configure it again…I would prefer fast access to the buttons, maybe an application for my device where I have a set of buttons and some reasonable interface”
3	Bad shared configuration Good shared use	“I would not want people to touch my wirings”. “If someone used my envisioned wiring as it is I would be ok. I would want some sort of

3	Security	authentication or some sort of right to block someone from change”.
		<u>Participant 11 (M)</u>
	Blocking interface	*Trying to keep out of the way of the projector* 02:46
4	Interface layout issues	“Why is the delete button in the corner? Why not in the center?”
		Tried to turn off the other object that was connected 6:49
	Middle finger, Multi-tap	*Tapping multiple times with middle finger* 07:07
		(Mark) Hovering effect that accidentally triggers another action
	Top down on touch	“Maybe because of the hover effects I have to come from above” *Demonstrates the above tap* 11:23
2	Positive feedback (idea) Remote	“[I like the internet of things idea…the projections and also the remote switches]”
2	Restrictive (NFC) Negative feedback (interaction) Overwhelming Mobile	“I think [there was] a boundary where you had to hold the phone in a particular way”. “It’s not that intuitive” “I still cannot visualise the idea of connecting all the devices and seeing everything on the wall. So I’m kinda overwhelmed”. “I assumed you could control everything remotely. If I need to go to the device to connect I really don’t see the point. If I have it on my smartphone I could just swipe with a line and they’re connected. If I need to go to the wall, as a lazy person I really don’t see the point.”
	Bad shared	“would be less private. wouldn’t be the discrete way how I want it to be”
		<u>Participant 1 (M)</u>
1	Turns phone	*Holding phone in a more natural way (upside down)* 03:00
	Two fingers	*Uses two fingers* *deletes lines without much trouble* *encounters bug where the physical does not influence the virtual*
	Deletion confusion	*had to think for sometime to remember the bin function* 9:35
	Two modalities	“Sometimes I didn’t consider…because this

1	confusion Overlap to delete Touch troubles (few)	[points to VS] and this is an interface [points to PS], but why should I use the other interface to disconnect the other interface" (Like 13-Ant) "Would have made the connection again to remove it…they are kind of two different interfaces". "I was considering when connecting the TV and radio that they also turn on both. They belong together…" "It has problems to recognise the buttons"
		(Mark)hover problem
3	Feedback (slow speed)	"Maybe a hardware problem…I don't want to wait too long for it to activate".
		(Mark)the importance of feedback and responsiveness is still prevalent in the pre-configuration phase and once one has the configuration already in memory
	Bad shared Security	"Maybe I would feel safe when it's only possible with my smartphone or fingerprint pressing". "I don't want other people to mess around with my connection"
		<u>Participant 2 (F)</u>
		Was ok with stepping in front of projection, had to move when checking result 00:30
	Right hand, multiple fingers	*Used right hand to use virtual interface*
	Continuous flow	*Did the direct-to-next object to try and connect three devices*
6	Left hand, three fingers	*Switches to left hand. Three fingers* 03:35
1	Distant force	*Uses some force from a distance to disconnect* 04:50
	Right hand	*Switches to right hand again to click VS* 05:50
	Blocking interface Mobile	"Visualisation was quite good. There were some parts where I was like right now [blocks projector] where is the lamp is connected to". "Possibility to do it remotely…I don't want to stand up and go here and click there…"
		(Mark) Remote desktop
	Positive feedback	"Worked quite well with the Kinect. Quite cool"
		(Mark) Buttons were clustered together in earlier version
	Connection	"With the lines visible it is clear enough"

	understanding	
		Participant 3 (M)
	Left hand	*Uses left hand while right hand is in the pocket* 01:10
	Colour	“Why is one red and the other [top line colour]?”
	Right hand	*Used right hand to click interface* 01:53
	Hover effect	*Accidentally did the hover tap* 2:58
	Switching VS sensible	“Line keeps appearing and disappearing when I change…that makes sense” 04:05
	Left hand with smartphone	*Used the left hand with the smartphone in it to delete the line*
	Blocking interface	“Main reason to not use it would be obstruction”
	Feedback (vib)	“I like…as soon as I select something I get haptic feedback”
	Touch (simple good) Deletion confusion (bad)	“It’s cool for me to be able to cycle through the virtual appliances, but what I found it hard to get was to first select and select and then touch the bin”
	Alternative buttons	“Maybe a way to select it somehow or a context menu”
	Alt. Object representation	“Placement is good in the vicinity of the actual objects”. “What would be nice would be the silhouette of the object”
		(Mark) some sort of shapely representation of the object
2	Customizability	“Being able to grab something and move it somewhere else”
	Interface layout issues	“Having animations…I can see it is from there…I have a sense that an interaction took place”
	Good shared (so-so)	“If I use the system with other people then the interaction space would need to be quite big”. “If I’m comfortable standing right next to other person…”
		Participant 5 - Jo
2	Physical awkwardness	*Bent down to turn on all the devices individually* 02:20
	Two fingers	*Two fingers while still bent down* 03:15
		(Mark) back issues
	Top down on touch	*Fingers facing down, avoiding occlusion* 04:10

	Connection understanding (delayed)	*Surprised at seeing a different line on VS change* 5:38
	Left hand (physical)	*All four physical devices connected and uses left hand to turn on physical radio* 06:45
	Blocking interface Disconnect confusion	*Took some time to see the disconnect working due to occlusion* 07:30
		(Mark) room for improvement for feedback
4	Connection understanding Feedback (vibration) Feedback (visual)	"Cool…immediate connections and nice feedback. Vibration feedback"
	Feedback (slow speed)	"Touch interface to the left was sometimes laggy"
	Feedback (visual) Unnatural	"…[the circle changes and that indicates activation]…I wouldn't have known that intuitively". "Other than that I think I understood how the interface worked"
	Good shared (safety)	"I would trust the people. So far the [appliances] are not critical or dangerous or costly".
4	Warning	"Maybe not to have a specific mode for secure interaction, but it's helpful to display a warning if there's something that's more costly".
	Warning	"Delayed activation - popup saying "Garage door is open""
		<u>Participant 6 (M)</u>
	Blocking interface	"I'm kinda in the way" 02:45
	Hover effect	*Hover problem* 03:20
	Touch (good)	*Apparent preference for the touch interface* 04:40
		(Mark) playful, not tried before
	Hover effect	*Actually selected the washing machine without 'pressing' the wall* 05:24
	Connection understanding	*Did notice that the 'activation period' had stopped* 05:55
	Mobile (NFC)	"Nice to do it with the smartphone to activate the stuff"
	Interface above object Labelling	"Would be cooler if it was above the stuff"."Two points and having them labelled"
	Blocking interface	"Sensor worked…standing in front of the line of sight of the projector"

	Labelling	“[Washing machine and dishwasher]…wasn’t clear to me”
	Interface layout issues	“Line originating from the off button”.
		(Mark)off-putting line origins
	Labelling Interface layout issues	”Label of the devices [and what it’s connected to], list of things that you can switch right and left”. *Describes have a preview selection L & R*
	Good shared Security	“Security settings for shared devices…a private printer that you can show off but you can have security settings for your own devices, no one that can turn it off on the shared projection”
		<u>Participant 7 (M)</u>
	Touch issues	*Some problems just switching. Had to move finger a little to the left* 03:35
	Continuous flow	*Follow through expectation* 06:50
	(Ignorance/Experience)	“First time with smart house concept”
	Positive feedback	“I like the idea…to project onto [any surface] in the house”
	Connection understanding (benefit)	*Talking about other devices in the house* “The connection I have between devices…is missing”….”But here it’s clear”.
		(Mark) A physical system has been created where lines exist between nodes. Why is the left side designed differently? When there is only one device you’ve connected in a room and all the other devices in the house are connected to this one part, the system once again gets cluttered.
	Customizability	“I don’t care where the lamp is placed. I can move the lamp *physically moved the lamp*…follow the device”
	NFC not preferred	*Really wanted to not use the smartphone but touch the wall nodes and interface*
	Good shared	“No difference…in sharing physical devices and this virtual one. It’s just sharing with your family”
	Interface above object Small children	*Like ChrG mentioned small children & placing the interface higher up so that they can’t reach it*
	Interface above object Rooms Additional buttons	*Demonstrates having a room selection above the existing interface* 18:15
	Singular vs. separate interfaces	“You can combine all the things and provide the choice...It’s fine when the physical devices are

		placed together...but if I want to operate something at the same time in this room and the other room I have to go here [mimes interaction] then move to the other room." Continuous describing having the system in a singular place as KinectIt does.
		(Mark) when one has access to a display with visible connections shown to all people, this might simply be enough. The method of showing the connections may be simply unnecessary. Something that would require quite a bit of additional empirical evidence to prove. Can't just say that and expect it to be true.
		<u>Participant 8 (M)</u>
1	Exaggerated Blocking interface Top down on touch	*Brought the smartphone very much from above, then had to move out of the way to see the result*
	Deletion confusion	*Trouble deleting* 02:40
	Two fingers Hover effect (worked) Leaning (comfortable)	*Double finger - hovering actually worked here. Was able to stand at a comfortable distance* 03:00
	Feedback (visual) (unclear)	*Expected that activating the physical object and then pressing the virtual power button was required* 03:40
	Feedback (slow speed) Warnings (background checking)	*System configuration error - participant tried to resolve it by continuously connecting other objects* 04:00
	Continuous flow	*Seemed to want to try the follow-through* 07:55
	Leaning One/Two fingers	*Leaning with 1-2 fingers to delete the line*
2	Top down on touch (off) Fingers 90 degrees (L/R) (rotate)	*Upside-down finger selection for on/off - fingers rotate when on L/R buttons*
	Negative feedback Unnatural (unintuitive)	"I didn't really understand it. It's not very intuitive"
	Labelling	"I didn't know the washing machine was a washing machine and not just an icon for…like a metaphor for something"
	Mobile (unclear)	*Explained that when they touched with a smartphone that they thought it would turn on*
		(Mark) giving the option for the user to turn on the

		device directly on NFC touching
2	Feedback (vib) Feedback (visual) Connection understanding Object occlusion (radio)	“I liked the vibration feedback because that was sort of immediate and also the rings around the buttons.”.”I’m not sure I can…yeah I can sort of map them” “I would have missed the fourth one [Radio]”
	Pre-config Good shared Mobile	“That’s ok. As long as I have to be there to turn it on or preset to turn it on.” “I can also see it as a remote interface”
		<u>Participant 9 (M)</u>
		Right handed
	Left hand NFC + right hand touch Hover effect	*Used left hand with phone and right hand to delete the line, also accidentally activate Virtual on (hover effect)*
	Blocking interface	*Tries to get out of the way of the projection* 03:30
	Physical awkwardness Leaning	*Some bending needed to reach delete* 04:30
	Right hand	“Because usually I do most of the work with my right hand so that’s why I was [reaching over]”
	Top down on touch	*Fingers are upside down* 05:44
	Labelling	*Was confused what the dishwasher was* “My fridge is exactly like that!”
	Learning Connection understanding	“Usually we deal with the physical things…now it’s changing the concept from physical to perceptual”. “I don’t know if it’s about the place or the thing”. “It would take some time to get used to it. As a person you would repeat the things and then start to remember.”
	Connection understanding Deletion confusion	“It can be tricky to delete the lines…connecting is quite simple.”
	Touch (delete)	“I press the line and it just disconnects”
		(Mark)could be an alternative to the bin as a third function
	Learning	“I think it would need some education for the person at home”. “Its a technology, so you have to learn the things…maybe some basic steps, initial knowledge and then it will be used, and quite easy” .“Initially for me for one minute or two minutes I couldn’t see what actually I am doing…

		but now it just looks familiar"
	Blocking interfaces Object occlusion	"Might be a problem if it's not within the line of sight. You have to move physically"
	Warnings	"In a sense it's secure. With plugs you might have a short circuit"
1	Culture	*Talks about using it in a country where wired cabling and the environment could effect the wires*
		<u>Participant 13 (M)</u>
	Hover effect	*Hover effects accidentally clicking to activate the connection process*
	Two fingers, rotated, Left hand	*Hand is rotated and touched with two fingers*
	Right hand	*Switched to right hand* 04:36
	Touch (nodes)	*Initially tried to touch the wall* 06:15
	Deletion confusion	*Tried clicking the bin icon* 08:12
	Leaning	*Some leaning, but successful deletion* 9:40
1	Purpose	"It was complicated at first…especially the connection, I didn't understand why".
1	Unnatural Inconsistent Two modalities	"After one try I realised how to work with [VS]". "[Two modalities] are inconsistent….as a user it's a bit complicated"
	Good shared Remote	"I could have it open". "For having the speaker and TV especially….it's really perfect. I don't have to have 3 or 4 remote controls."

A.5 – Consent Form

Bauhaus-Universität Weimar	Contact: Mark Eisenberg (mark.eisenberg@uni-weimar.de)

IoT interfaces study - Consent Form 2017

Voluntary Nature of the Study / Confidentiality:
Participation in this study is entirely voluntary. You may refuse to continue at any point without giving reasons. You may ask the researchers any questions about the research and the study. You may decide not to answer our questions or ask for your data to be withdrawn.

Your names will never be connected to the research results; a pseudonym will be used for identification purposes. Information that would make it possible to identify any participant will not be included in any sort of report, or disclosed outside the project unless explicitly granted – below you can choose whether we for instance may utilise any pictures or audio recordings where you may be recognized.

Consent to Participate

I, ____________________ (print name)

agree to participate in this research project.

I have had the purposes of the study explained to me.
I have been given the opportunity to ask questions about the study and have had these answered satisfactorily.
I have been informed that I may refuse to participate at any point by simply saying so.
I have been assured that my confidentiality will be protected.
I agree that the information that I provide can be used for educational or research purposes, including publication, with my personal data being handled confidentially (privacy).

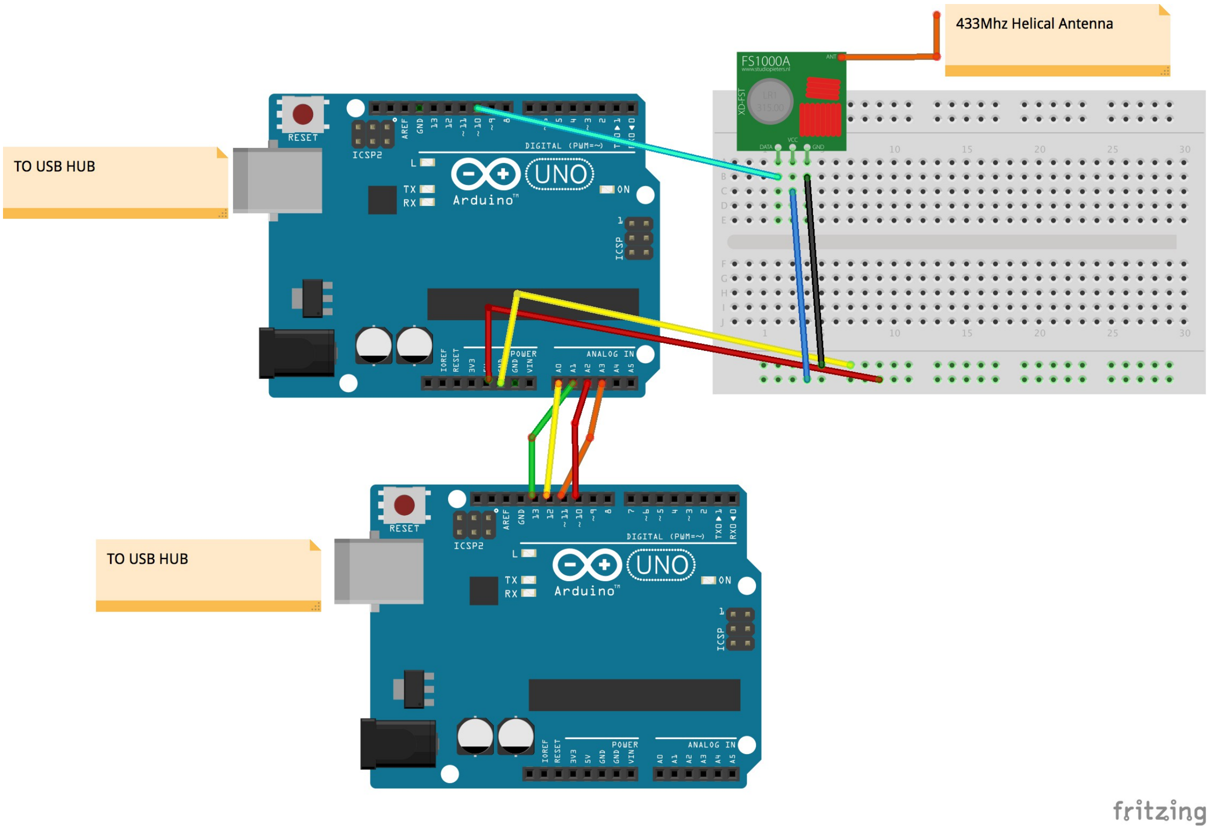
I O do (please mark)
O do not
agree that still images of myself can be used in presentations and publications, which may appear online

I understand that if I have any concerns or difficulties I can contact:

Contact: Mark Eisenberg (mark.eisenberg@uni-weimar.de)

Signed: ____________________ Date: __________

A.6 – Circuit Diagram



A.7 – Project Plan

My tasks on Mark Thesis

		Task	Sub Tasks	Assignee	Est. Hour	Start Date	Due Date	Task Prog.
0	ME	Read papers		Mark Eisenberg	-	24/May	01/Jun	100%
1	ME	Proof of concept		Mark Eisenberg	-	25/May	30/May	100%
2	ME	Explore interactive scree...		Mark Eisenberg	-	26/May	08/Jun	100%
3	ME	Develop room layout		Mark Eisenberg	-	29/May	08/Jun	100%
4	ME	Gatherpurchase appliances		Mark Eisenberg	-	29/May	08/Jun	100%
5	ME	Gather study materials, p...		Mark Eisenberg	-	05/Jun	12/Jun	100%
6	ME	Conduct pre-study		Mark Eisenberg	-	09/Jun	21/Jun	100%
7	ME	Web Dev		Mark Eisenberg	-	19/Jun	26/Jun	100%
8	ME	Develop prototype IoT int...		Mark Eisenberg	-	23/Jun	21/Jul	100%
9	ME	Develop improved protot...		Mark Eisenberg	-	24/Jul	08/Sep	100%
10	ME	Conduct second user stu...		Mark Eisenberg	-	06/Sep	21/Sep	100%
11	ME	Analysis		Mark Eisenberg	-	22/Sep	06/Oct	100%
	ME	Draft report		Mark Eisenberg	-	02/Oct	01/Nov	100%
13		Layout		Unassigned	-	09/Oct	13/Oct	100%
14		Further fitting research		Unassigned	-	09/Oct	24/Oct	100%
15		Content		Unassigned	-	09/Oct	01/Nov	0%
	ME	Final report		Mark Eisenberg	-	02/Nov	16/Nov	0%
17		Proof read		Unassigned	-	02/Nov	16/Nov	0%
18		Add content		Unassigned	-	02/Nov	16/Nov	0%
19	ME	Presentation preparation		Mark Eisenberg	-	10/Nov	16/Nov	0%
20	ME	Thesis defence		Mark Eisenberg	-	16/Nov	22/Nov	0%

A.8 – Stationary List

List of stationary used in Low-Fidelity prototyping
Origami Paper
Scissors
Pencil Compass
String
Sticky tack
Black marker

A.9 – Estimated pricing for materials

Products	Price
4 x Radio Frequency power adapters	€12
RF transmitters and receivers	€7
10 x 433 Mhz Helical Antennas	€5
Nyko Zoom Lens	€15
4 x Amazon Dash Buttons	€5 x 4
Smartphone Mount/ Selfie Stick	€15
4 x NFC sticker sets (24 stickers total)	€20
Microsoft Kinect	~€35 – Laboratory Kinect used for Project
Projector	Price varies
Total (approx.)	*€129 + Projector*

A.10 – Instructions for HomeNodes setup

1. Connect Arduinos and Kinect Camera to PC
2. Start XAMPP server
3. Launch Spacebrew via console
4. Start Breakout server and connect to the corresponding Arduino port
5. Launch HiveMQ via the batch file
6. Launch OpenHab via the batch file
7. Open index.html, hello.html,nfc.html and the Spacebrew admin dashboard (sb.html) in a browser
8. Start the SpaceNFCSender.pde with Processing
9. Start UbiDisplay, configure and calibrate three screens on the wall. Touch should be left of the NFC screen. The third screen for the hello.html can be at any position.
10. Drag the URLs from the browser into the corresponding space on the interface wall
11. Change the resolution of the screens by double clicking on the display on the left within UbiDisplay, such that the interface aligns sufficiently to the objects in the room. The screens can be refreshed by bringing the mouse to the second display, right clicking and then clicking Refresh.
12. Use the Spacebrew admin dashboard in the browser to connect x>y
13. Test the system to see if the Amazon Dash buttons, NFC activation and TouchWall work. NFC can be controlled using the Sensors2OSC application for Android.
14. If the system is working and can be replicated for another session, save the project within UbiDisplays. Steps 9-11 can be mostly skipped this way.

A.11 – Additional Pictures and Photos

Fig. A.1 – RF Adapters locations, three on table, fourth in wall socket.

Fig. A.2 – Testing the Kinect at a different position

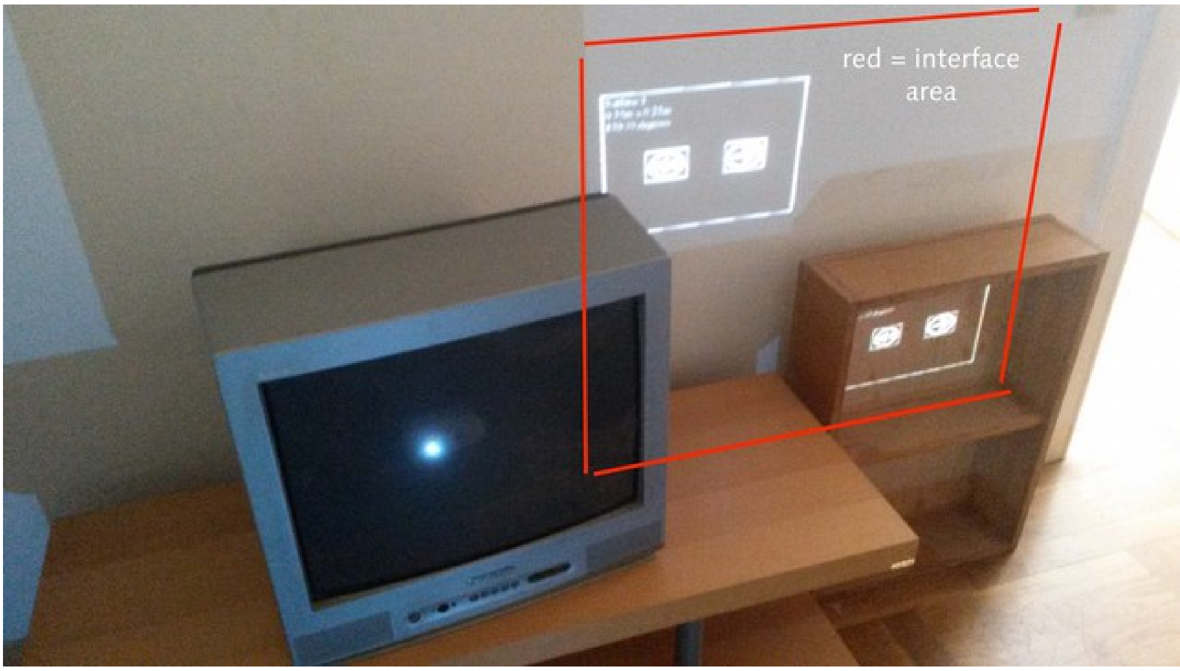


Fig. A.3 – Limitations of UbiDisplays from direct angle

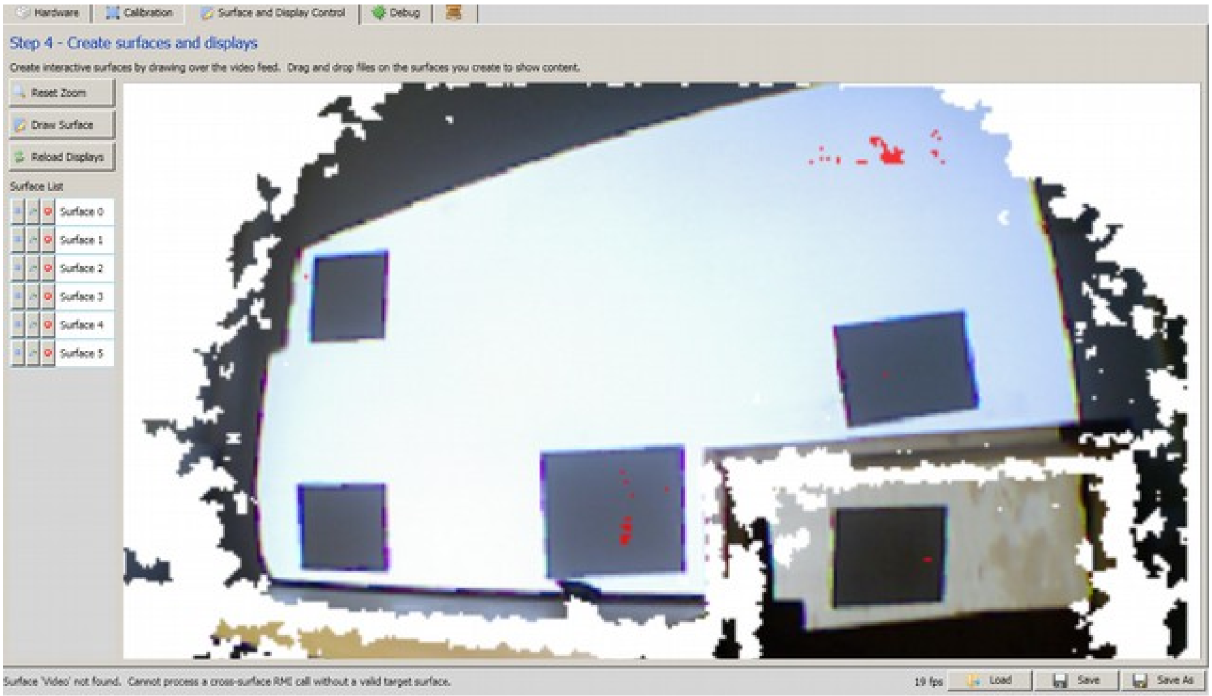


Fig. A.4 – Test with Nyko Zoom Lens and test touch surface. Red noise is a result of what UbiDisplays considers to be a non-flat surface.

Fig. A.5 – Early HomeNodes setup

Fig. A.6 – Final positioning of Kinect camera at an angle to the wall (~2 meters)

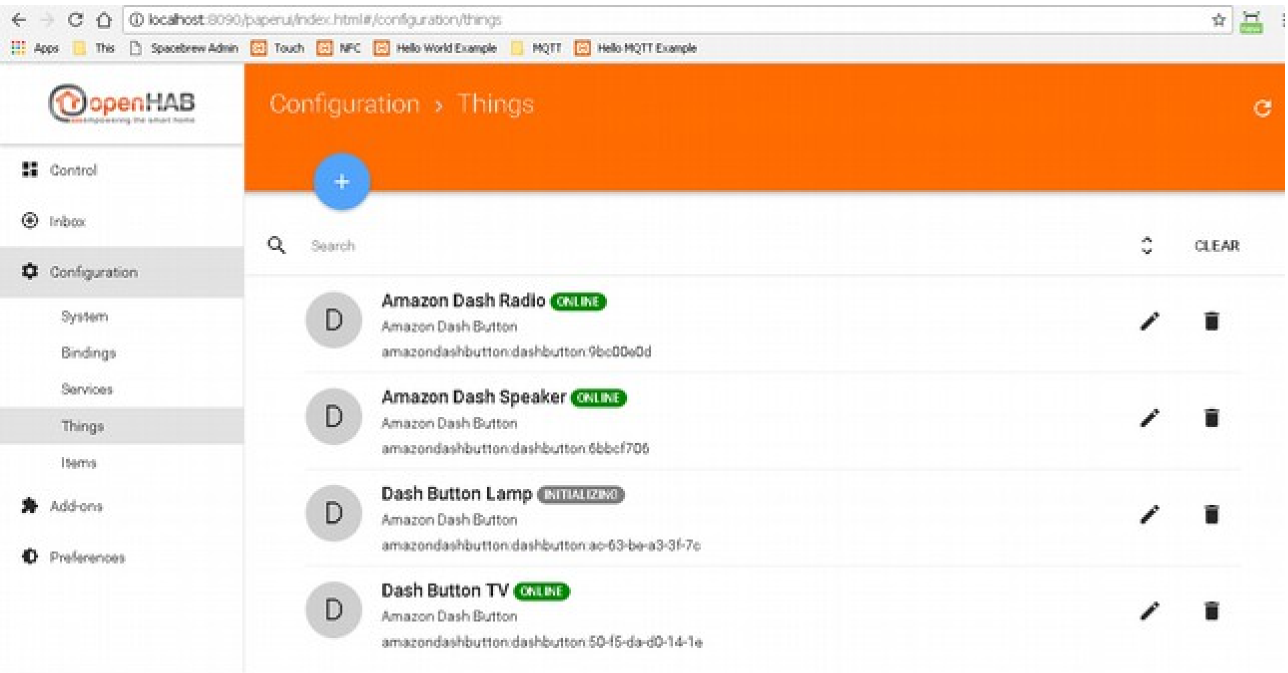


Fig. A.7 – OpenHAB dashboard with Amazon Dash buttons. The Dash buttons that say 'initializing' must be re-added to OpenHAB before HomeNodes can be used.

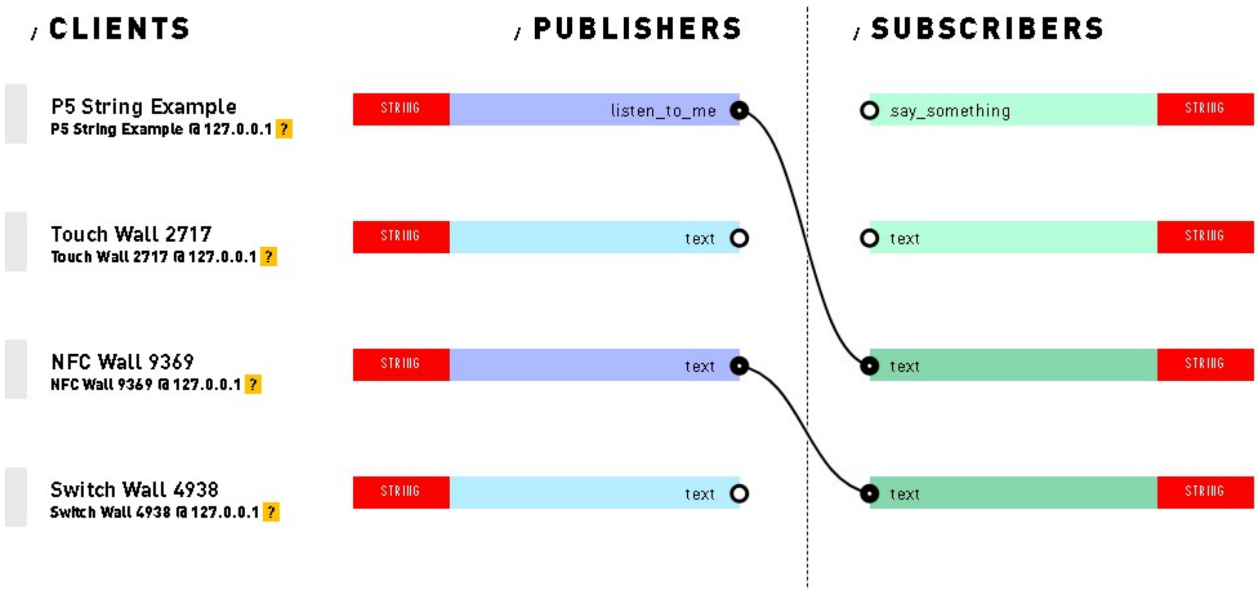


Fig. A.8 - Spacebrew admin

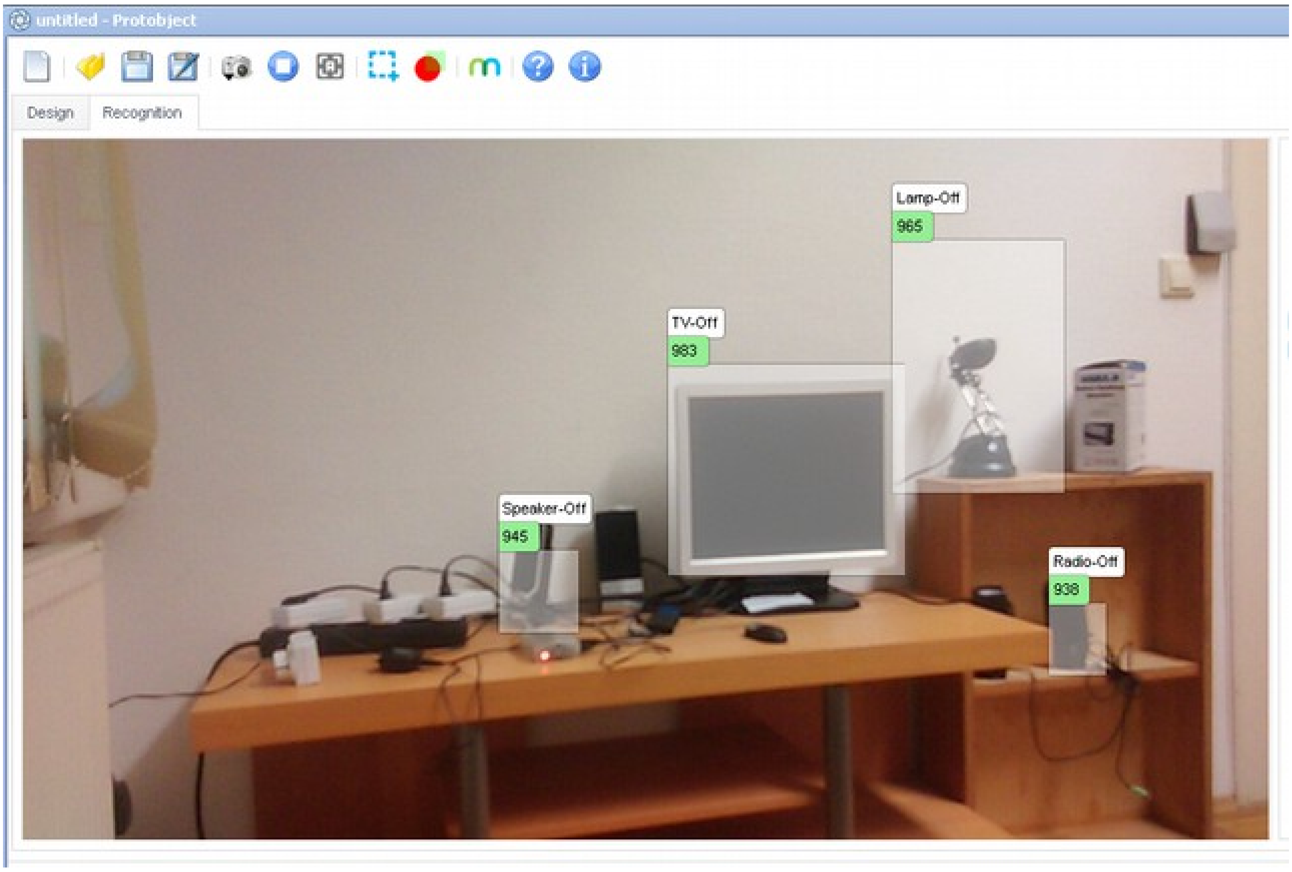


Fig. A.9 - Protobject testing