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Feasibility Study of Ubiquitous Interaction Concepts

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Abstract

There are all sorts of consumer electronics in a home environment. Using "apps" to interact with each device is neither feasible nor practical in an ubicomp future. Prototyping and evaluating interaction concepts for this future is a challenge. This paper proposes four concepts for device discovery and device interaction implemented in a virtual environment. The interaction concepts were compared in a controlled experiment for evaluation and comparison.

Some statistically significant differences and subjective preferences could be observed in the quantitative and qualitative data respectively.

Overall, the results indicate that the proposed interaction concepts were found natural and easy to use.

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1. Introduction

In our home environment we surround ourselves with all sorts of devices: TVs, home entertainment systems, gaming consoles, digital photo frames etc. Forecasts predict an "Internet of Things" world where most devices can be remote controlled by users, or other devices through the Internet [1,2].

With constant miniaturization, devices of the future may not even have physical buttons or screens that allow direct interaction.

Imagine a home, with hundreds of connected devices serving the home and its residents. Using "apps" to interact with each device is neither feasible nor practical in such a home [3]. As of today interaction is heavily reliant on users' explicit actions: choosing what content to show, where to show it, how to show it and setting all preferences. Prototyping and evaluating interaction concepts beyond the current paradigm is a challenge, due to components that are undeveloped or not sufficiently advanced [4].

Many researches have studied ubicomp interaction by using paper prototyping [5] or a Wizard of Oz (WOZ) method i.e. where a human simulates missing parts of a system. For example, Lee at al. [6] used a modified WOZ setup, in a

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comfortable living room, where two subjects were involved. One of the subjects interacted with gestures while the other subject interpreted and acted upon them.

This paper presents two concepts for device discovery and two for device interaction implemented in a virtual home environment. The implemented concepts are simple but functional for device interaction in an ubicomp environment.

The concepts were carefully designed to make use of devices such as TV, tablet, game console and printer, since Consolvo et al.[7] found these devices to be the most frequently available devices.

The objective of the proposed interaction concepts is to support higher degrees of implicit human - computer interaction, aided by mobile and wearable devices, which the authors think will simplify both discovery and interaction with consumer electronics (CEs). This will yield in a low cognitive workload for the users and more intuitive and natural interaction.

To evaluate and compare the interaction concepts, a controlled experiment was performed. This experiment consisted of participants performing tasks inside a virtual environment (VE) in order to generate quantitative as well as qualitative data.

The main contribution of this paper, is to present four interaction concepts developed with virtual reality (VR) for interaction in ubicomp environments.

In the next section relevant related work is presented. Followed by method, results, discussion, conclusions and future work.

2. Related Work

Mark Weiser's vision stated in the 1990's has inspired many researchers, "The most profound technologies are those that disappear."[8]. This statement has been and still is used as an important guideline for researchers within ubicomp[9]. Currently many researchers in the ubicomp community are targeting aspects such as context-aware computing and ubiquitous intelligence i.e. computational intelligence that is part of both the physical and the digital worlds[9,10]. However, two areas that needs more attention is prototyping and evaluating ubicomp interaction and new input methods[4].

2.1. Tools for prototyping ubicomp interaction

Carter et al.[11] highlighted that developers have a limited set of tools including sketches, paper prototype mock-ups and WOZ simulations. Recently, platforms such as Arduino has been used for prototyping ubicomp applications. The integration of software and hardware with Arduino makes it relatively easy for anyone to prototype new concepts[12]. For example Amarino[13] is a useful tool that can be used for communication between smartphone and tangible devices such as clothes, furniture etc.

Examples of research tools that uses a WOZ method include ConWIZ[14], a WOZ tool with a mobile application capable of controlling simulations of contextual objects such as fans, lights etc. Fleury et al.[15] also used a WOZ setup to evaluate four different methods for transferring video content from a smartphone to a TV screen.

Other tools used for ubiquitous prototyping include[16,17,18,6].

2.2. Evaluating input methods for ubicomp interaction

There are several input methods suitable for ubicomp interaction that have been studied and evaluated over the past three decades. For example the "put that there" experiment[19] is an early study of using gestural input and voice commands. Wilson and Oliver[20] also used gesture and voice commands in one of their user interface systems. Wilson and Oliver present four systems[20] that uses both explicit and implicit interaction.

Consolvo et al. evaluated ubicomp applications by using the experience sampling method i.e. participants filled out questionnaires every day by responding to alerts. One finding was that it is reasonable to create scenarios for ubicomp applications where the user takes advantage of an available output device, particularly if the device is a television set, desktop computer or printer[7]. Similar output devices have been used in this paper. Other ubicomp interaction research developing and evaluating concepts include[7,21,22].

The listed research based on WOZ have the drawback of relying too heavily on the wizard not accidentally injecting noise in the test result.

The four concepts which are presented in this paper are real working concepts in a VE. Therefore, the results is dependent on the participant and the system during the experiments, allowing for replicapable testing.

3. Method

The four interaction concepts were developed in an iterative design process which included bodystorming, paper prototyping and a focus group session.

To build a system for execution and visualization of the interaction concepts, off-the-shelf input/output devices were used. These were thoroughly tested in different configurations and their advantages and disadvantages were reflected upon.

Through exploratory development the final system components were chosen (these are discussed in 3.2). This setup made it possible to map the physical world to the VE (Fig. 1).

Fig. 1. The VE

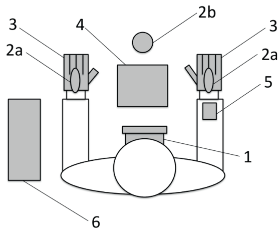

Fig. 2. System components

3.1. Design

The main input for conceptual design was bodystorming, when an idea for a concept was formulated, paper prototyping and wireframing would ensue to formulate use cases and to validate the ideas.

A number of prototypes were implemented using the system components at hand, the implementation of these prototypes made further improvement of the concepts easier since they were somewhat tangible.

3.2. System

The system components (Fig. 2) used to evaluate the four interaction concepts include:

1. Oculus Rift Development Kit[23]. A VR head mounted display.

2. Razer Hydra[24]. A tracking system enabling tracking of position and orientation of the two wired controllers (2a) relative to the base station (2b). The controllers are attached to the back of the user's hands.

3. 5DT Data Glove 5 Ultra[25]. A motion capture glove, enabling tracking of finger joint flexion in real time.

4. Sony Xperia Tablet Z[26]. An Android 10" tablet. The tablet is placed in alignment with a tablet in the VE (Fig. 1). The tablet allows the system to capture and react to touch input from the user.

5. Android smartphone. This device is attached to the wrist of the user's dominant arm and is used to give haptic feedback through vibrations. The location of this feedback device is aligned with the virtual wristband in the VE (Fig. 1).

6. Desktop computer with a powerful graphics card. This computer executes and powers the VE through the use of the Unity[27] game engine.

The VE is a living room (Fig. 1) where the user is sitting down on a couch in front of a table. A tablet, one of the input devices, is lying on a table in front of the user. A TV where media can be played is hanging on the wall in front of the user. Other CEs including speakers, audio receiver, game console and printer, are located throughout the living room to let the user discover more devices. The user is presented with overlaid information while interacting with the VE. This augmentation may originate from a head mounted display or other technologies. The purpose of using augmentation is to give the user spatially placed visual feedback. The input methods in combination with the overlaid information was chosen to allow for prototyping a range of existing, as well as future, device combinations.

3.3. Interaction Concepts

The main objectives for the four interaction concepts were: *a*) Minimizing the disruptive and distracting use of multiple controllers/ terminals, for controlling CEs. This might lower the workload. *b*) Minimizing the overwhelming amount of explicit actions needed to decide what content to display and what device to display it on. This might make the interaction more natural and intuitive. *c*) To bridge the gap between the real and the digital world, making CEs an extension of the users.

3.3.1. Device Discovery

The main inspiration for the device discovery concepts stems from two important notions from Norman[28] that makes for good and consistent device discoverability. ”Discoverability: Is it possible to even figure out what actions are possible and where and how to perform them?” and ”Understanding: What does it all mean? How is the product supposed to be used? What do all the different controls and settings mean?”

The Gaze concept allows the user to discover the identity and location of CEs in the user’s vicinity by looking around (Fig. 3). The hardware system does not include a gaze tracking component, instead the center of the view is used as the focus of the user’s gaze. When a discoverable device is in view center for more than one second, a window with interaction possibilities on the focused device is displayed. When the device is no longer in focus, the window disappears.

Fig. 3. Device discovery – Gaze

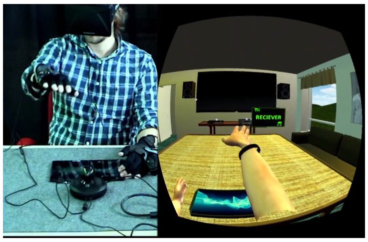

Fig. 4. Device discovery – Gesture

The Gesture concept allows the user to discover the identity and location of devices by moving the dominant hand in a scanning motion (Fig. 4). When a discoverable device is pointed at by the user’s hand for more than one second, the user receives vibration feedback to his/her wrist and a window with interaction possibilities of the device is displayed. When the device is no longer pointed towards, the window disappears.

3.3.2. Device interaction

Tablets are attributed to shared ownership[29], therefore a tablet is used in both implementations of the device interaction concepts.

The Grab concept allows the user to select a playback device with a grabbing gesture (Fig. 5). The user first selects an output device by reaching towards it with an open hand and then clenching the fist. If a device was correctly selected, the user receives vibration feedback to his/her wrist and the virtual wristband of the outstretched hand changes color according to the grabbed device. The device remains selected as long as the user keeps making a fist. The next step is to move the closed hand to the surface of a device with a touchscreen and open the closed fist. If the fist is opened in mid-air the grabbed device is deselected and the virtual wristband returns to its original color. By opening the hand on the tablet surface, the tablet renders a user interface (UI) for media playback.

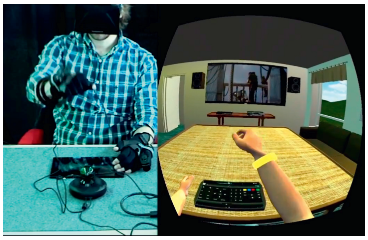

Fig. 5. Device interaction – Grab

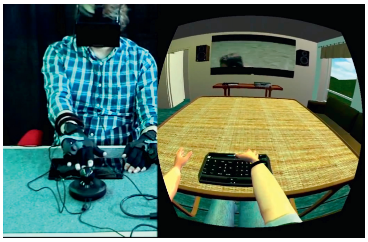

Fig. 6. Device interaction – Push

The push concept allows the user to first select media content and then select the output device by flicking the content towards it (Fig. 6). The UI allows the user to select and control the playback of the content.

A video of the interaction concepts can be seen at `http://goo.gl/zewYjm`.

3.4. Evaluation

For evaluation, a controlled experiment was performed in a fully equipped usability lab. The experiment consisted of two parts; one for the device discovery concepts and another for the device interaction concepts. For the purpose of analysis both audio and video was captured in the usability lab.

Participants were mainly university students with engineering background. 24 persons (9 female) participated in the device discovery part. Their mean age was 24.5 (19 - 37 years). There were 20 participants (9 female) in the device interaction part and their mean age was 23.8 (19 - 35 years). The device interaction participants were a subset of the device discovery group (due to technical problems, four participants' data could not be used).

Each test session consisted of five steps (Fig. 7) which in total lasted approximately one hour. The session started with the participant signing an informed consent form and filling out a background questionnaire. The questionnaire included participant age, gender, occupation and 3D gaming experience.

Next, a brief introduction to ubicomp was presented. Thereafter the participant was given approximately five minutes to try out the VR system to get familiarized with the environment.

After the participant was familiar with the system the usability test started. Each participant performed tests on all four interaction concepts. The order in which a concept was evaluated was counterbalanced in order to avoid learning effects. Task completion time, performed errors and error recovery time were recorded, during each test. Furthermore, multiple audio/video feeds from the usability lab and one video feed from the VR system was captured.

Upon completion of each task, the participant filled out a NASA-TLX questionnaire[30]. The questionnaire was followed by a short semi structured interview.

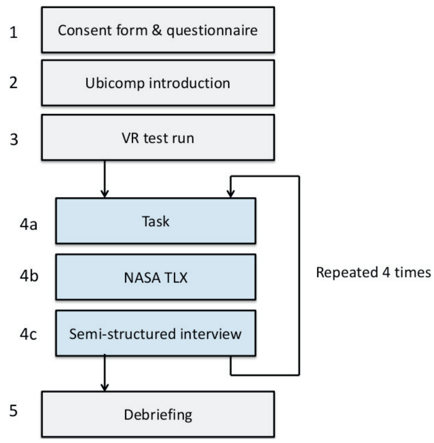

Fig. 7. Test session procedure

Since the tests were of two different characters (Device Discovery and Device Interaction) the participant would be given comparative questions after the second semi structured interview.

After the full test session the participant was debriefed in order to elicit further preference and evaluative statements.

Total perceived workload was calculated for each participant based on the NASA-TLX data. Correlation testing was performed on perceived workload and task completion time ($p < 0.05$). A Wilcoxon signed rank test for two paired samples ($p < 0.05$) was used to analyze the quantitative data and find out whether there were any significant differences between concepts. The participant's comments from the test session were transcribed and analyzed with individual quotes categorized and labeled in a table.

4. Results

This section presents quantitative and qualitative data from the experiments.

4.1. Quantitative

Moderate correlations were found for Gaze and Gesture regarding workload and time to complete task (Table 1). However, only small correlations can be seen for Grab and Push (Fig. 8, 9, 10, 11).

Table 1: Correlation of TLX Workload and Task completion time *p <0.05*

	Gaze	Gesture	Grab	Push
df	22	22	18	18
r	0.47	0.52	0.17	0.26

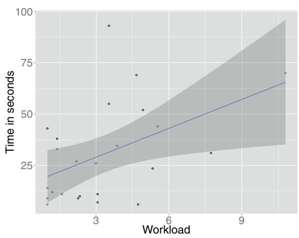

Fig. 8. Scatterplot – Gaze

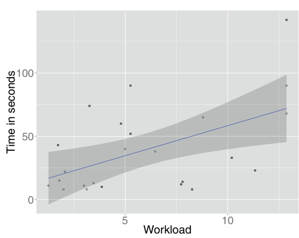

Fig. 9. Scatterplot – Gesture

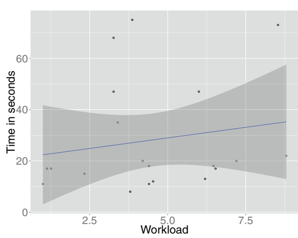

Fig. 10. Scatterplot – Grab

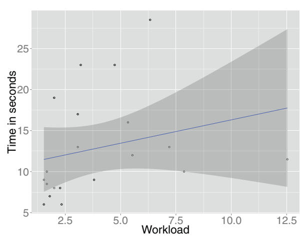

Fig. 11. Scatterplot – Push

For the two device discovery concepts, the mean NASA-TLX workload values (Gaze = 3.34, Gesture = 6.05 with median 3.03 and 5.13 respectively) were notably different (Fig. 12), with a significant difference between them ($Z = -3.40, p <0.05$). It is worth noting that there is a considerable significant difference in the perceived physical demand ($Z = 4.07, p <0.05$). With mean Gaze = 2.33, Gesture = 7.25 and a median of 1.5 and 5.5 respectively. In contrast, there is no statistical difference on perceived mental demand ($Z = -1.32, p <0.05$) with very similar means (Gaze = 4.13, Gesture = 4.92) but with large difference in median (2.5 and 5 respectively). There was no significant difference between Gaze and Gesture with regards to task completion time ($Z = -0.51, p <0.05$). With mean Gaze = 30.58, mean Gesture = 39.58 and median values of 26.5 and 28 respectively. With a range of (6 – 93) and (8 – 142) respectively.

For the two device interaction concepts, the mean NASA-TLX workload values (mean Grab = 4.72, mean Push = 4.19 with median 4.33 and 3.37 respectively) were not notably different (Fig. 13). Overall, the perceived workload was not significantly different between the two interaction concepts ($Z = 1.44, p <0.05$). There was no significant difference of the perceived physical demand ($Z = 1.66, p <0.05$). With mean values Grab = 5.45, Push = 4.45 and median 5.5 and 3 respectively. Furthermore no significant difference was found of the perceived mental demand ($Z = 0.40, p <0.05$). With mean Grab = 4.25, Push = 4.15 and median 4 and 3 respectively. However, there was a significant difference between grab and push with regards to task completion time ($Z = 2.39, p <0.05$). With a mean Grab = 28.20, Push = 12.88 and median 18 and 10.75 respectively. With a range (8 – 75) and (6 – 28.5) respectively.

No significant results were found considering error and error cost for any of the proposed concepts.

4.2. Qualitative

All qualitative data from the experiments were analysed by comparing their strengths and weaknesses. On the one hand the participants perceived the concepts being natural and intuitive. On the other hand, some attributes were stronger emphasised concerning each concept, these attributes are presented in Table 2.

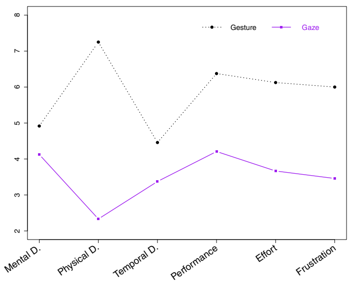

Fig. 12. Mean NASA-TLX values for device discovery

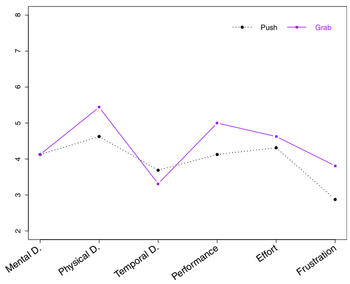

Fig. 13. Mean NASA-TLX values for device discovery

Table 2: Strengths/ Weakness Analysis

	Strengths	Weaknesses
Gaze	Natural, Intuitive, Convenient	Intrusive, Privacy Concerns
Gesture	Control, Precision, Secure	Socially awkward, Physically Demanding
Push	Convenient, Fast, Intuitive	Confusing, Lack of control when having several devices
Grab	Intuitive, In control	Awkward, Unnatural without a tangible device

5. Discussion

In this paper we have presented four interaction concepts for ubicomp, they were evaluated using immersive VR.

Overall, the results indicate that the users found the concepts natural and intuitive. Although statistically there were notable differences regarding how fast participants could finish their task, only small and moderate correlations were found between the task completion time and the perceived workload. This due to task completion time being affected by much more than the six categories in the NASA-TLX. For the device discovery concepts significant differences were found in perceived physical demand. Combining this with the qualitative data, one can make the assumption that higher demand not always is a bad thing. Whilst Gaze felt intrusive and raising privacy concerns, Gesture seemed to yield a feeling of being more in control and having higher security.

The Push and Grab concepts have similar characteristics which also can be seen in the NASA-TLX graph (Fig. 13). Further, in the case of Gaze and Gesture, the NASA-TLX graph(Fig. 13) were much more different, which accords well with the fact that these two interaction concepts are quite different as already discussed.

Nevertheless, the validity of an evaluation based on participants' perceptions and actions inside a VE must be carefully considered. One could argue that the proposed method constitutes a sort of Russian nested doll effect with ”a UI inside a UI”.

Although, while the suggested concepts are basic, they still are functional for ubicomp. System limitations that might have affected the participants are the cables and equipment that the users had to put on but also system limitation such as not having the possibility to lean forward or back. The user need to sit still and only move head, arms and fingers.

6. Conclusions and Future work

The main conclusion of the research described in this paper is that the four interaction concepts seems to be natural and easy to use. The concepts were developed on a very crude level and to make for deeper evaluation they need to be further explored. To further explore the proposed interaction concepts, more controlled experiments should be performed. Most importantly the debriefing needs to consist of more directed questions. And the number of participants needs to be greatly increased.

Acknowledgements

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