Ubiquitous Computing: By the People, For the People

Ali Ndiwalana, C. M. Chewar, Dillon Bussert, Jacob Somervell, D. Scott McCrickard
Center for HCI & Department of Computer Science
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0106 USA
{andiwala, cchewar, dbussert, jsomerve, mccricks}@cs.vt.edu

ABSTRACT

One of the challenges in building and evaluating ubiquitous computing systems emanates from the fact that they generally have been built to showcase technological innovation without considering how to foretell whether and how people will eventually accept them in their lives. In this study, participants are introduced to the notion of ubiquitous computing via a scenario-centric presentation including basic everyday objects imbued with some computational power to convey information. Through a detailed survey, participants provide feedback relating to their impressions, rating the performance of each interface on a number of metrics and making comparisons between the ubiquitous and desktop interfaces. We inspire them to think of new ways to use existing ubiquitous interfaces to support their current and possible information needs, as well as better interfaces that can convey this information.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Evaluation/methodology*; *Prototyping; User-centered design*

General Terms

Human Factors, Design, Experimentation.

Keywords

Invisible computing, user preferences, attitude survey

1. INTRODUCTION

With the common proliferation of smaller and low bandwidth computing devices coupled with advances in wireless communications, Weiser's vision [16][17][18] of calm and ubiquitous computing (ubicomp) is gradually being realized. Nearly 10 years ago, he predicted that computing today will be revolutionized by single platforms supporting multiple users, which would most successfully serve users as "*invisible*" systems. By invisible he meant that the technology stays out of the way of the task and does not draw attention to itself. However, while researchers push the technology envelope to develop novel, invisible systems not ready for the general public, prototypes often stop in the research lab [2]. Similarly, ubicomp systems are usually not built to address specific human needs, but are touted for providing more ephemeral benefits such as peripheral awareness [8]. These factors make it difficult to understand the motivations behind use as well as presence [6] of ubicomp systems in people's lives. This compounds the challenges of evaluating systems in their proper context and understanding their impact—a prerequisite for progress in any research area.

Ubicomp represents an attempt to move computing beyond the confines of tool usage, where a person has to sit behind a computer placed on a desk in a particular location, towards a pervasive penetration of technology into the environment, where we work and live with potentially far-reaching effects. The attempt to seamlessly integrate computing into our daily activities requires new application design and software infrastructural challenges [3], and would undoubtedly result in new ways of interaction, as well as social norms, forcing us to reorganize the way we do things now [9].

Abowd and Mynatt [2] provide a pinnacle discussion for ubicomp development, highlighting many research challenges and needs for this field. They also provide a valuable characterization of ubicomp interfaces that support *everyday computing*: natural, off the desktop interaction between humans and information, context-aware systems that adapt to situation variables, and applications that automate capture of daily experiences. The focus of our work is on natural interfaces. Responding to the challenges that they recognize relating to the design and evaluation within the ubicomp paradigm, they articulate the need to create "a compelling story," by relying on real or perceived user needs to motivate the development of ubicomp technology. We also recognize that this will provide both a demonstrational vehicle for ubicomp research as well as a basis to evaluate the impact of ubicomp interfaces on the daily life of intended users.

Ubicomp technology is beginning to arouse commercial interest as industry explores better ways to turn its investments in telecommunication infrastructure into profit, by leveraging gadgets that provide contextual information and services. Scenario building [4] has the potential to generate and prioritize ideas for new products and services, in addition to identifying the possible users and contexts of use.

Besides understanding why and how users would interact with ubicomp systems, we recognize the importance of learning some of the factors that might influence their decisions to adopt the technology. To this end, we carried out a study where participants were introduced to the notion of ubiquitous computing via a scenario-centric [4] presentation including basic everyday objects imbued with some computational power to convey information. Through a detailed survey, participants provided feedback relating to their impressions.

ACMSE '03, March 7-8, 2003, Savannah, Georgia.

Our survey is an initial step in a requirements analysis process that probes issues impacting the use and acceptance of ubicomp systems in people's everyday lives. We are inspired by the Georgia Tech Graphics, Visualization and Usability (GVU) center's WWW User Survey [5] and its ability to track web demographics, culture, user attitudes, and usage patterns over a long period of time—a priceless resource for any emerging field. This resource provides a good overview of how Internet usage trends have evolved over time. Like the GVU survey, we plan to expand our sampling over time to understand changing attitudes towards ubiquitous computing technologies and their adoption.

The remainder of this paper is organized as follows: we first look at some of the other work related to this study; we then describe the methodology for our study, present the results and discuss them. Finally we present conclusions and directions for future work.

2. RELATED WORK

The main themes within human-computer interaction that we draw upon for our study are the scenario-centric method to determine user needs and investigate predictors of user adoption of ubicomp technology. In this section, we discuss some of the work related to these themes.

A common approach in ubiquitous computing research is to build and deploy working systems and then observe them in use to generate ideas for iterative deployment. This has produced numerous insights on how the systems could be improved, as well as their affects on users and social interactions. A good example is the Classroom 2000 [1], an instrumented classroom environment that captures live lectures in a form that can be accessed later. An iterative design process involving users in an actual classroom was used to generate progressive refinements. Qualitative data was collected from surveys and quantitative data from usage logs. Comparative studies were done to determine the impact of the system on student performance, which exhibited only marginal improvement despite the costly iterative re-engineering process.

User-centered scenarios, on the other hand, have been used in a variety of ways to generate design ideas for new products and services [7][13], in addition to validating and prioritizing user needs [10]. The scenarios are stories about situations involving actors (users) and their interaction with the environment to satisfy information needs [4]. They enable researchers and designers to develop functional models of real-life use of new products and to present design ideas to the users, which could be difficult or expensive to prototype or simulate otherwise. For example, from a user study, Mikkonen et al [13] identify elderly communication needs that rely on wireless devices and services to facilitate independent living. They articulate the user feedback into concept scenarios that reflect potential services and are used to further determine feasibility and prioritization for a group of elderly users. As a similar example, Ikonen & Rentto [7] explore the feasibility of a personal navigation system with a group of potential users, aided by the help of scenarios. Kankainen [10] presents a third example in his description of a multi-level scenario-based process that helps validate and prioritize user needs generated from user testing. The last two studies are reports presented at workshops that have not yet been followed up with published literature.

Hallnäs and Redström [6] poignantly argue that, as ubicomp systems start to become a part of our daily life, designers of these systems will need to look beyond mere "use"—functional aspects of their systems. They argue that it is insufficient to think in terms of the confines of tool usage, the conventional view of human-computer interaction, evaluated in terms of efficiency, simplicity of use, and ease of learning. Instead, they implore consideration of "presence," which they define as the "existential definitions of a thing" basing how we invite and accept it into our lives. They make strong arguments for rethinking traditional human-computer design and evaluation as "computer systems change from being tools for specific use to everyday things present in our lives," and the need to "change focus from design for efficient use to design for meaningful presence." Our study is designed to validate their views by investigating how conventional usability aspects might affect user attitudes towards ubicomp technology adoption.

3. METHODOLOGY

In this study, participants are introduced to the notion of ubiquitous computing with the help of basic everyday objects imbued with the ability to convey information. We used the Real World Interface (RWI) toolkit [11][12] to extend the capabilities of three everyday objects. The *infoLAMP* uses the brightness of a light to convey information, the *dataFAN* uses wind speed from a fan, and the *hapticCHAIR* uses vibration from a cushion.

Figure 1. infoLAMP is a physical device that can depict digital information via a serial or USB port using a transmission protocol like X10. The Real World Interface toolkit allows easy association of information sources (such as the Internet) with physical device properties. In this case, brightness levels are adjusted to depict

Participants compare these ubiquitous interfaces with two desktop interfaces that display the same information: a simple number display *counter* and a progress *indicator* bar, allowing us to glean some insight as to how the two types of interfaces might differ.

Our hypotheses for the study may seem to be obvious statements consistent with mainstream HCI thinking, however, we feel that based on the concerns raised by Abowd and Mynatt [2] and Hallnäs and Redström [6], they are important to verify for the ubiquitous design paradigm:

1: People prefer desktop over ubiquitous interfaces to display everyday information.

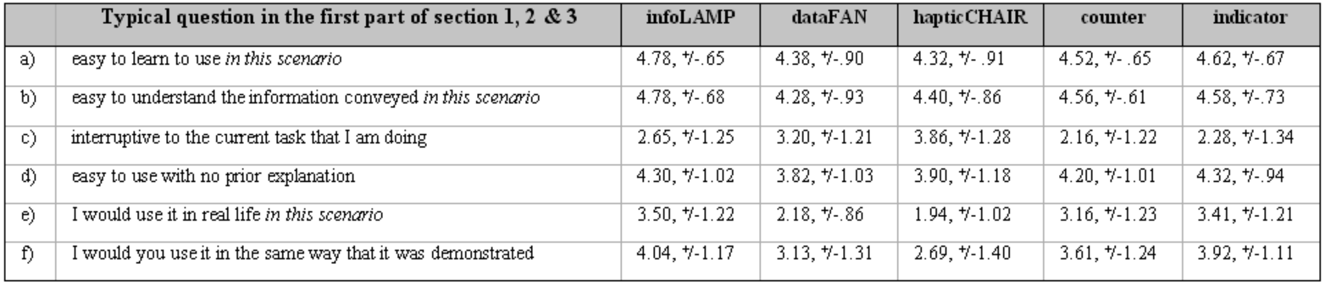
2: People will be more willing to start using ubiquitous interfaces if they perceive them as trustworthy and intuitive.

3: The effort required to understand information conveyed by the ubiquitous interfaces inhibits willingness to use.

4: People who have never heard of ubicomp before will be less trusting of and want to be less dependent on ubicomp systems, impacting their willingness to adopt ubiquitous interfaces.

We describe the user population and the experimental session, in which our results were gathered.

Table 1. Some of the typical questions from the beginning portion of the first three sections of the questionnaire that help rate the performance of each of the tested devices in each of the scenarios. Average results from scenario 2 are shown.



	Typical question in the first part of section 1, 2 & 3	infoLAMP	dataFAN	hapticCHAIR	counter	indicator
a)	easy to learn to use *in this scenario*	4.78, +/-.65	4.38, +/-.90	4.32, +/- .91	4.52, +/- .65	4.62, +/-.67
b)	easy to understand the information conveyed *in this scenario*	4.78, +/-.68	4.28, +/-.93	4.40, +/-.86	4.56, +/-.61	4.58, +/-.73
c)	interruptive to the current task that I am doing	2.65, +/-1.25	3.20, +/-1.21	3.86, +/-1.28	2.16, +/-1.22	2.28, +/-1.34
d)	easy to use with no prior explanation	4.30, +/-1.02	3.82, +/-1.03	3.90, +/-1.18	4.20, +/-1.01	4.32, +/-.94
e)	I would use it in real life *in this scenario*	3.50, +/-1.22	2.18, +/-.86	1.94, +/-1.02	3.16, +/-1.23	3.41, +/-1.21
f)	I would you use it in the same way that it was demonstrated	4.04, +/-1.17	3.13, +/-1.31	2.69, +/-1.40	3.61, +/-1.24	3.92, +/-1.11

3.1 User population

In conducting this study, we chose to focus on a population familiar with emerging technology that will more likely be at the forefront of ubicomp early adoption. Therefore our participants are 50 undergraduate computer science students who received class credit for their time. There are 5 females and 45 males, who range in age from 19 to 31. Most of them reported being very familiar with computers (43/50), while the rest felt fairly familiar (7/50). They own a range of mobile computing devices that include laptops, cellular phones, Personal digital assistants (PDAs), miniature MP3 players, etc. In the pre-study questions, the majority indicated not having heard of the term "ubiquitous computing" before (34/50), while some (4/50) were not sure. Of those who had heard of the term (12/50), two were not sure of its meaning.

3.2 Experimental session

Participants were studied in groups of eight, although each session was conducted in identical fashion. During an experimental session, participants are introduced to all of the interfaces. Everyday information is conveyed to the participants on the various devices within the context of a scenario that helped situate the interaction. The scenarios were selected to reflect a variety of information needs, and they include monitoring of three different types of information: 1) *outdoor temperature*, 2) *online buddy status* for instant messaging, and 3) *progress in performing a timed task*.

Scenario 1. In this scenario, participants were told to imagine themselves seated before a computer, engaged in an editing task. They were then asked to monitor outdoor temperature to determine changes over time with each of the five devices being tested.

Scenario 2. Like in scenario 1, they performed a similar primary task. However, they were asked to use the devices being tested to monitor online buddy status of someone they are interested in communicating with via instant messaging.

Scenario 3. In the final scenario, the primary task changed, requiring participants to imagine themselves engaged in a timed online examination. They were then asked to monitor their progress in relation to the amount of time that had passed using each of the five devices being tested.

Detailed feedback is collected via a questionnaire, which consists of four subsections and 154 questions in total. After each scenario demonstration, participants provided feedback by completing a section of the questionnaire. This involved rating the performance of each interface, as well as comparing them on a number of metrics that include: *learnability* or ease of learning, *intuitiveness* or easy of use with no prior explanation, *interruptiveness* and *simplicity* of effort required to understand the information conveyed. The first three sections are similar, and are used to collect feedback for each of the scenarios, while the fourth section is more general and probes their experience in all three scenarios. Each section consists of 46 questions and is repeated for all three scenarios. Table 1 shows a typical beginning portion for the first three sections, with the results from scenario 2 for each of the devices that we tested.[1]

Participants conclude the study session with a general section consisting of 10 questions that asks for their thoughts on a variety of social aspects pertinent to ubicomp [1][9] and inspires them to think of new ways to use these interfaces. We were specifically interested to know how they felt their current and possible information needs should be supported, as well as better interface designs that would convey this information. Participants were free to ask questions at any time during the session, which normally lasted for about one hour.

4. RESULTS

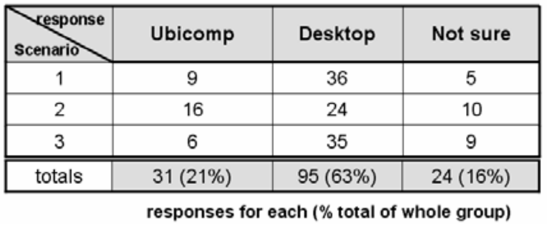
We present our results in terms of each of the four hypotheses. We elucidate some of the interesting findings in the discussion section that follows.

The first hypothesis was generally supported, although ubiquitous interfaces showed promise in specific situations. Based on the questionnaire results for all three scenarios, 63% of responses exhibited preference for desktop interfaces, while 21% showed preference for ubiquitous interfaces, and 16% were unsure, as indicated in Table 2. However, focusing on monitoring online buddy status (scenario 2) 22 of the 50 participants expressed preference for the infoLAMP, favoring the ubiquitous device over other interface choices. User comments elaborated on this finding, recognizing preference for peripheral information delivery: "not having to focus on the desktop," "provides information you need," "you don't have to read it or look at it." Preference for ubiquitous interfaces was weak in all of the other scenarios.

---

[1] All surveys questions are available online at http://research.cs.vt.edu/ns/surveys/ubicomp/ubicomp1.htm

Table 2. Number of participants indicating preference for each device type in each scenario. The totals and overall percentages in parentheses for all the participants are shown at the bottom.

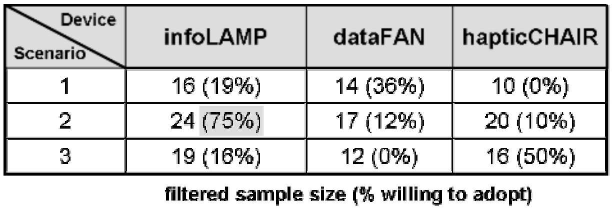


Scenario \ response	Ubicomp	Desktop	Not sure
1	9	36	5
2	16	24	10
3	6	35	9
totals	31 (21%)	95 (63%)	24 (16%)

responses for each (% total of whole group)

To probe the second hypothesis, we filtered our data to include only the 27 participants who indicated "sufficient trust to be able to use" ubicomp systems. Of these, we filtered further to identify cases where participants agreed that a ubicomp device was "easy to use with no prior explanation." This sample consisted of trusting participants that found the particular ubicomp device to be intuitive in use. Qualifying sample sizes and the percentage of these cases where the participant was willing to start using that particular device is shown in Table 3. Had hypothesis 2 held, the percentages in the table would approach 100%. Surprisingly, only the infoLAMP in scenario 2 showed a (weak) correlation between trust and intuitiveness as a predictor for willingness to adopt.

Table 3. Number of participants indicating sufficient trust to use each device in each scenario. In parentheses is the percent of those participants who indicated a willingness to adopt the device.



Scenario \ Device	infoLAMP	dataFAN	hapticCHAIR
1	16 (19%)	14 (36%)	10 (0%)
2	24 (75%)	17 (12%)	20 (10%)
3	19 (16%)	12 (0%)	16 (50%)

filtered sample size (% willing to adopt)

For the third hypothesis, we assessed the effort required to understand the information conveyed in terms of three factors—responses on questions related to learnability, intuitiveness, and interruptiveness. With each device, we looked for patterns related to these responses and the outcome of the willingness-to-adopt question. For instance, in 62 of the 68 occurrences that participants indicated negative responses to both learnability and intuitiveness, they were also unwilling to adopt. Likewise, two or more unfavorable responses in the effort-required factors are a strong predictor of not being willing to adopt (108/114 occurrences). However, it is surprising that when we compare the predicted unwillingness to adopt versus the actual unwillingness to adopt, we find that the third hypothesis is a weak predictor and dependent on the scenarios. In scenarios 1 and 3, the factors predicted 57/123 and 54/130 cases of unwillingness to adopt, while scenario 2 predicted only 6/108 cases. The results are depicted in Table 4.

Table 4. Ratio of predicted unwillingness to adopt based on hypothesis 3 criteria versus actual unwillingness to adopt. Note that Scenarios 1 and 3 exhibit much better prediction success, although this hypothesis is not supported by any scenarios.

Scenario \ Device	infoLAMP	dataFAN	hapticCHAIR	Total
1	12/40	14/36	31/47	57/123 (46%)
2	1/18	3/46	2/44	6/108 (6%)
3	17/42	24/50	13/38	54/130 (42%)

For the fourth hypothesis, we filtered our data to include only the 34 participants who indicated having not "heard of the term ubiquitous computing." From the sample, 28 did "sufficiently trust" ubicomp systems to be able to use them and 6 did not exhibit agreement that they trust these systems. Of the 28 who sufficiently trusted ubicomp systems to be able to use them, 17 were worried about becoming fully dependent on the reliable operation of ubicomp technology and 11 were not. Of the 6 who did not "sufficiently trust", 4 did not mind dependency, while 2 did. Figure 2 depicts how our user samples are distributed between these hypothesis' conditions. The only group that directly meets the conditions of hypothesis 4 is indicated with a dashed outline. If Hypothesis 4 had been supported, both of these participants would not have indicated willingness to any of the ubicomp devices demonstrated in the study. However, both of these participants agreed that they would want to use multiple ubicomp devices in their daily lives, providing evidence that is contrary to hypothesis 4. It is interesting that the other subgroups had lower percentages of willingness to adopt at least one of the three devices.

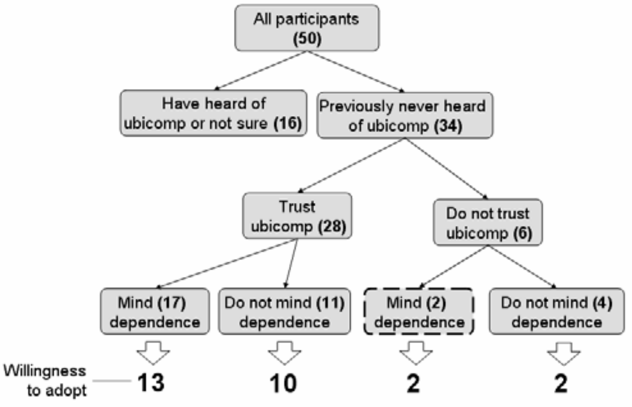


Figure 2. User samples distributed between hypothesis 4 conditions. The group with the dashed outline indicates the only participants who met the hypothesis conditions. The hypothesis implies that these participants would not have been willing to adopt any of the ubicomp devices.

5. DISCUSSION

Our user survey provided some much needed introspection into the attitudes and tendencies of our target population. We were quite surprised at many of the results despite the suggestions of these trends within existing literature. We expected that many of the usability notions from mainstream human-computer interaction will be reflected more in the participant responses. However, this was not the case.

The preference for desktop interfaces over ubiquitous devices in hypothesis 1 might be explained by the fact that most participants have previously used desktop interfaces to keep track of similar information. However, this does not explain the unexpectedly strong preference for the infoLAMP in scenario 2. We suspect this may relate to the kind of information being conveyed in that scenario—unlike the ratio values conveyed in the other two scenarios, scenario 2 depicted binary categorical buddy statuses. While this implies successful information mapping for the infoLAMP, we feel the result has deeper implications due to the lack of preference for the counter interface (similar information mapping). Factoring in the participant comments, the infoLAMP was truly appreciated for its ability to liberate information delivery from the desktop platform and blend in with the user's environment—this exemplifies success of a ubicomp system.

Although hypotheses 2, 3 and 4 seem to be obvious extensions of human-computer interaction thought, it is most interesting that they do not hold true for predicting acceptance of ubicomp systems. In other words, trustworthy, intuitive, easy to use devices were not readily accepted by users that frequently use computers, personal digital assistants, and other electronic gadgets. Perhaps this finding highlights the importance of identifying good application areas for ubicomp systems, understandable given their potentially intrusive nature (particularly the haptic devices). This suggests the ubiquitous computing paradigm must not be measured in terms of the traditional; usability metrics, but must focus on other features of use. While this has been noted by other researchers [2][6], our study empirically validates this critical notion.

Based on our experience in conducting this user survey we found that using scenarios to get feedback from potential users is an excellent and inexpensive way that generates and prioritizes ideas for new products and services, in addition to focussing the actual contexts of use. While the existing literature we discussed suggested benefits of this approach, we were uncertain from these accounts whether it would be suitable for probing barriers to ubicomp adoption. Likewise, we were initially hesitant with using the prototypes to demonstrate features, fearing that users would not be able to fully appreciate the potential of a device integrated within the actual context of use. Neither of these initial apprehensions materialized in the study. Realizing this provides excitement about the rapid prototyping features of systems such as the Real World Interfaces (RWI) toolkit described by [11].

6. CONCLUSIONS & FUTURE WORK

The key findings of this study are summarized as follows:

- Ubicomp systems can be preferred over desktop interfaces in certain situations.
- Predicting acceptance of ubicomp systems transcends usage characteristics.

The performance of the infoLAMP is an outlier in all three hypotheses, raising questions about its differences from the other ubiquitous interfaces and providing a strong foundation for further inquiry. Participants provided many new ideas for alternate ubicomp interfaces, some of which will be integrated in future testing. Since learnability, intuitiveness, interruptiveness, or trust were not predictors of user acceptance, we must use successful systems such as the infoLAMP to determine better predictors.

It will be very interesting to see how results from this same study conducted in future years with similar populations will change over time. We predict that future of these young participants will be increasingly more familiar with ubicomp systems and have stronger predispositions that impact willingness to adopt them in their daily lives. We also plan to add additional scenarios and questions that probe new hypotheses for better predictors and include expanded situations of use. For instance, it is already common to see people walking around with wearable computing and communication devices that allow ubiquitous access to information—many of which are context-aware or allow capture of daily experiences. We would like to understand better how a user's expected interaction with these devices differs from the natural, embedded interfaces that we targeted in this study. While we have already recognized that traditional measures of usability can not readily be applied to real world interfaces, we suspect that metrics for systems within these other two classes would need even more revision, considering the social implications that surround their use and interaction. It will be exciting to see how the opportunities, created by understanding user expectations better, are harnessed by system developers for the betterment of humanity.

7. REFERENCES

[1] Abowd, G.D. Classroom 2000: An experiment with the instrumentation of a living educational environment. IBM Systems Journal, vol 38. 1999.

[2] Abowd, G.D. & Mynatt, E.D. Charting past, present, and future research in ubiquitous computing, ACM Transactions on Computer-Human Interaction (TOCHI), v.7 n.1, p.29-58, March 2000.

[3] Banavar, G. & Bernstein, A. Software infrastructure and design challenges for ubiquitous computing applications. Commun. ACM 45, 12, 92-96. ACM Press 2002.

[4] Carroll, J. M. & Rosson, M.B. Human-computer interaction scenarios as a design representation. Proceedings of the 23rd Annual Hawaii International Conference on Systems Sciences, 555-561, 1995.Los Alamitos, CA. IEEE Computer Society Press.

[5] GVU's WWW User surveys. http://www.cc.gatech.edu/gvu/user_surveys/

[6] Hallnäs, L. & Redström, J. From use to presence: On the expressions and aesthetics of everyday computational things. ACM Transactions on Computer-Human Interaction (TOCHI), v.9 n.2, p106-124, ACM Press 2002.

[7] Ikonen, V. & Rentto, K. Scenario Evaluations for Ubiquitous Computing – Stories Come True? Position paper for the Ubicomp 2002 conference workshop Evaluation Methods for Ubiquitous Computing. Goteborg, Sweden. October 2002.

[8] Ishii H. and Ulmer B. Tangible bits: Towards seamless interfaces between people, bits, and atoms. In Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI '97), pages 234–241, Atlanta, GA, Mar. 1997.

[9] Jessup, M.L. & Robey, D. The relevance of social issues in ubiquitous computing environments, Commun. ACM 45, 12, 88-91. ACM Press 2002.

[10] Kankainen, T. User Centered Scenario Evaluation and Validation of Ubiquitous Computing Concepts. Position paper for the Ubicomp 2001 conference workshop Evaluation Methods for Ubiquitous Computing. 2001.

[11] McCrickard, D.S., Wrighton, D., and Bussert, D. Supporting the Construction of Real World Interfaces. Tech note in Proceedings of the 2002 IEEE Symposia on Human Centric Computing Languages and Environments (HCC 2002), Arlington VA, September 2002.

[12] McCrickard, D.S., Bussert, D., and Wrighton, D. A Toolkit for the Construction of Real World Interfaces. In the proceedings of the 2003 ACM South East Conference, Savannah GA, March 2003.

[13] Mikkonen, M. and Väyrynen, S. Ikonen, V. & Heikkilä, M. O. User and Concept Studies as Tools in Developing Mobile Communication Services for the Elderly. Personal and Ubiquitous Computing. Vol 6, n 2, 113-124, Springer-Verlag, 2002.

[14] Rosson, M.B. and Carroll, J.M. Usability Engineering: Scenario-Based Development of Human-Computer Interaction. San Francisco. Morgan Kaufmann. 2002.

[15] Thackara, J. The design challenge of pervasive computing. Interactions, 8(3):46–52, May/June 2001.

[16] Weiser, M. The computer for the 21st century. Sci. Am. 265, 3, 94–104. Sept. 1991

[17] Weiser, M. Some computer science issues in ubiquitous computing. Commun. ACM 36, 7, 75–84. 1993

[18] Weiser, M. Ubiquitous computing. IEEE Computer, 26(10):71–72, 1993.