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# A Smart Home Experience using Egocentric Interaction Design Principles

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*Abstract*— **The landscape of ubiquitous computing comprising of numerous interconnected computing devices seamlessly integrated within everyday environments introduces a need to do research beyond human-computer interaction: in particular incorporate human-environment interaction. While the technological advancements have driven the field of ubiquitous computing, the ultimate focus should center on human agents and their experience in interacting with ubiquitous computing systems offering smart services. This paper describes egocentric interaction as a human body-centered interaction paradigm for framing human-environment interaction using proximity and human perception. A smart home environment capable of supporting physical-virtual activities and designed according to egocentric interaction principles is used for exploring the human experience it offers, yielding positive results as a proof of concept.**

*Index Terms*—**Egocentric Interaction, Ubiquitous Computing, Human-Computer Interaction, Context-Aware Computing, Smart Home and Human Experience.**

## I. Introduction

Technological advancements over the last 10 years have been influential in moving towards Mark Weiser's vision of ubiquitous computing [1] where everyday physical environments are populated with numerous, interconnected and invisible computing devices offering smart services. However, there is a need to do more research on establishing novel models for human interaction with multiple computing devices offering services in parallel, questioning the restrictions imposed by traditional interaction models on confining human interactions to a single targeted computing device. Also, since ubiquitous computing takes place in everyday physical environments that are dynamic with multitude of contextual factors constantly changing and affecting human experience in interacting with computing devices, further research on human experience evaluation focusing on ubiquitous computing systems is a need. Multiple computing devices providing continuous access to virtual environments, their information and services might leave human agents with cognitive overload if left unfiltered and affect human experience. Ubiquitous computing provides the opportunities to explore novel forms of physical interaction that usually takes place around devices and human agents where proximity plays a key role in filtering information and services. Can such an approach create positive human experience?

In this paper, we described egocentric interaction as a novel interaction paradigm suitable for ubiquitous computing environments. Egocentric interaction is a human-centered spatial model of interaction where the spatial dimensions are determined by a human agent's perception and action possibilities at a particular moment in time. The spatial model referred to as the situative space model capture information content that changes dynamically based on human mobility and the resources available in close proximity. While the technological advancements play a key role in realizing such novel interaction paradigms through the development of prototypes as proof of concept, the ultimate success of an interaction paradigm is determined by the human experience it offers in supporting human activities. This paper attempts to explore the human experience that egocentric interaction principles offer within a smart home context. While human experience focusing on the physical-virtual equity principle was already explored in our earlier work [2], the work presented in this paper views egocentric interaction design principles as a whole within the easy ADL home [2, 3], a living laboratory smart home for ubiquitous computing research. Considering the scope of this paper, further information about the technological details in developing the easy ADL home including the sensing, communication and interaction infrastructures are described elsewhere [2-5]. While existing work on human experience evaluation have typically focused on mobile computing environments, this work is novel in porting human experience evaluation to ubiquitous computing environments offering additional challenges and contributing along the experimental lines.

## II. Egocentric Interaction

Egocentric interaction is a body-centric interaction-modeling framework (as opposed to device-centric) that incorporates physical and virtual objects of interest on the basis of proximity and human perception [6] (refer to Fig. 1). It extends and modifies the classical user-centered approach in Human-Computer Interaction (HCI) on several points, including:

- *Situatedness:* Acknowledges the primacy of the agent's current bodily situation at each point in time in guiding and constraining the agent's behavior. The situation is the agent's natural vantage point: selecting what can be perceived and attended to, and limiting what can be performed.
- *Attention to the complete local environment:* Makes it a point to take the whole environment into consideration, not just a single targeted artifact or system.
- *The proximity principle:* Makes the assumption that proximity plays a fundamental role in determining what can

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be done, what events signify, and what agents are up to.

- *Changeability of environment and agent–environment relationship:* Takes into account agents' more or less constant movements of head, hands, sense organs, and body, locally and through the environment, as well as agents' constant rearrangements and modifications of various parts of the environment.
- *The physical-virtual equity principle:* It is neither biased towards interaction with "virtual," immaterial data objects (classical HCI), nor towards interaction with physical objects and machines (classical ergonomics and HMI, Human–Machine Interaction): it pays equal attention to virtual and physical objects, circumstances, and agents.

The term "egocentric" refers to the human body and mind of a specific human individual that (literally) acts as the center of reference to which all modeling is anchored. In the context of this article, the term should not be taken as a synonym for "selfish" or other similar higher-level personality traits but instead as the lower-level approach which human agents in general are forced to adopt to perceive and act in an environment based on their senses and cognitive abilities, even when working in groups and with shared goals.

### *A. Situative Space Model*

The situative space model acts as a corner stone for facilitating egocentric interaction. It is intended to capture what a specific human agent can perceive and not perceive, reach and not reach, at any given moment in time. This model is for the emerging egocentric interaction paradigm what the virtual desktop is for the PC/WIMP (Window, Icon, Menu, and Pointing device) interaction paradigm: more or less everything of interest to a specific human agent is assumed to, and supposed to, happen here. The situative space model is useful in framing a human agent's environment into objects and events of interest (both physical and virtual), and the ones that can be discarded for the moment. One of the challenges in facilitating and supporting human activities using ubiquitous computing is not in the lack but the excessive availability of information and services that needs to be filtered in a context-aware manner [7]. The situative space model developed based on human situatedness and their proximity to objects, uses human body as a natural vantage point for filtering objects of interest from the ones that are irrelevant at a given moment in time. It should be noted that the situative space model is human-centered, but not subjective; they are principally aimed at allowing objective determination for automated tracking purposes. A more extensive description of the situative space model and the approaches to automatically track it can be found elsewhere [8, 4, 5].

The situative space model is comprised of two important spaces namely *Perception Space (PS)* and *Action Space (AS).* The perception space is the space around a human that can be perceived by the human at each moment in time and varies continuously with the human agent's movement of body and body parts. The perception space encompasses multiple modalities including visual and audial modalities with different operating range and directional resolution depending on the modality. Refer to [4] for more information about the modality variations within the situative spaces. The action space is the space around the human that is currently accessible for performing actions. Note that it could be both physical actions performed by interacting with physical objects, and virtual actions performed by selecting and manipulating virtual objects using multiple modalities including speech and gestures [9]. The physical reach of the human determines the operating range for physical action space, while the range for virtual action space is determined by mediator access to virtual objects. Since many actions require perception to be efficient or even effective at all, action space is qualitatively affected by the current shape of the perception space and is usually a subset of the perception space. In terms of physical proximity to a human body, the distance range of perception space is usually larger than that of action space.

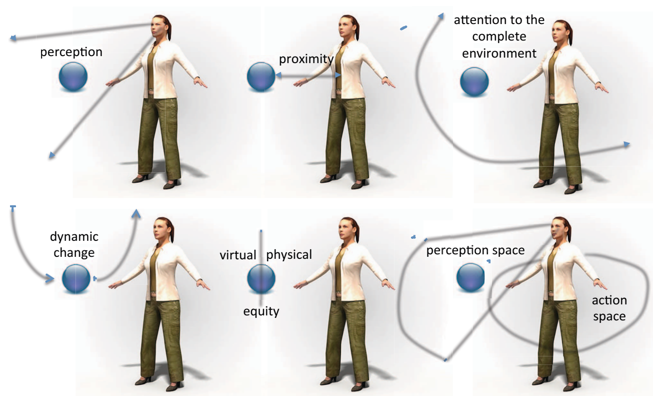


Fig. 1. Egocentric interaction design principles.

### *B. Achieving Physical-Virtual Equity*

One of the primary goals of ubiquitous computing is to enhance the support offered to humans in performing both physical and virtual activities. With more and more computers pervading everyday human environments, there are two phenomena that will be common in the future:

- Everyday physical activities are mediated by computing devices.
- Explosion of novel virtual activities that take place in everyday physical context.

Ubiquitous computing environments that could accommodate the above mentioned activity types should be designed using a Physical-Virtual framework [9] where the transition from the physical aspect to the virtual aspect and the vice-versa are made easier. Such a mixed-reality setting removes the bias towards the physical context (often researched in context-aware computing) or the virtual context. In an attempt to achieve physical-virtual equity, the following modeling stance is taken.

- *Virtual objects and mediators instead of interactive devices:* Input and output devices are viewed as mediators through which virtual objects are accessed. The purpose and function of mediators is that of expanding the action space and perception space of a given human agent.
- *Action and perception instead of input and output:* The modeled human individual needs to be viewed as an agent that can move about in a mixed-reality environment, not as a "user" performing a dialogue with a computer. The agent should be able to perform both physical and virtual activities simultaneously and with ease. If we take the physical-virtual equity principle seriously, also the classical HCI concepts of input and output need to be reconsidered. We suggest substituting the concepts of (device) "input" and "output"

with (human agent) "action" and "perception".

### C. Activity-Centeredness

Human agents perform activities in an environment by manipulating objects in it. Objects relevant to their current activity are usually present within the situative spaces [10] either by human locomotion to the location where such relevant objects are present (like moving to the kitchen to prepare breakfast), or by bringing in the objects to the location of the activity (like bringing in the newspaper to the sofa set or the dining table to read morning news depending on the context). Such a process can be commonly observed while a human performs physical activities. Taking inspiration from it to facilitate virtual activities using the situative space model is a challenge worth investigating. For instance, of all the virtual objects that are in the world space at a particular moment in time, only certain virtual objects qualify to be a part of a human agent's perception and action spaces. Taking the current activity context for filtering virtual objects and services is useful in facilitating human activities.

### D. Related Work

The Euclidean space around computing devices and human agents has become an important design factor in exploring the future of human-computer interaction within mobile and ubiquitous computing environments. Tangible user interfaces [11], embodied interaction [12], and context-aware systems [7] represent and explore different aspects of this space. While such research fields have made significant contributions over the years, we are still far from creating an overarching model for how future post-WIMP (windows, icon, menu, pointing device) human-computer interaction dialogues should be, heavily influenced by the properties of the physical space surrounding objects and human agents. Modeling *auras* defined as the spatial regions around objects or human agents for facilitating human-computer interaction was initially used in the virtual world. Benford and Fahlen [13] described a spatial model of interaction among virtual objects using spatial metrics like proximity and orientation. The model addressed multi-user and collaborative applications in virtual reality and hypermedia.

The mobile and ubiquitous computing community largely explores location modeling including the modeling of auras in the physical world. Many of these works address the problem of determining the set of objects and/or human agents who are capable of interacting with each other at a given time based on their individual spatial relationships. Addressing such a challenge is critical since simultaneous inclusion of all objects within an interaction model creates computational and cognitive overload. Approaches that are device-centered include *Digital Aura* [14] that supports proximal interaction among mobile devices in physical environments where the radius of the aura boundary is fixed for all devices irrespective of the varied spatial relationships that devices could share among themselves in the physical world. The physical range of the wireless technology used like Bluetooth, Radio Frequency Identification (RFID) and Infrared Data Association (IrDA) regulates this approach. Moving beyond pure physical proximity to include the notion of awareness for facilitating interaction among co-located devices is described in Q-Aura [15] where natural mechanisms in the physical world like orientation and movement are used in facilitating interaction. Relate system [16] facilitates multi-user and multi-device interactions based on spatial relations among mobile computing devices tracked using ultrasound technology. Spatial relations include distance, angle, direction (i.e. to the left, right, in front of, and behind), and movement (i.e. moving towards or moving away). Approaches that are human-centered include the Aura project [17] that appropriately selects the resources available at the location visited by a human agent depending on the task to be facilitated. Nomadic radio [18] uses a spatial model centered on a human agent in providing audio messaging that is contextually adapted according to message priority, human attention, activity context and environmental context.

The five dimensions of proxemics namely distance, orientation, movement, identity and location are described as part of proxemic interactions suitable for ubiquitous computing in [19]. While the term proxemics in general includes social interaction [20], proximity is probably a better term to describe such interactions. While many of the earlier mentioned related works evaluate their systems from a technological perspective, the notion of human experience is often forgotten.

## III. Human Experience Exploration

To fully assess the value of egocentric interaction (or similar emerging interaction paradigms) as a tool for facilitating human interaction within ubiquitous computing environments is hard. An approach that evaluates the technological aspects of a proof of concept prototype alone is not sufficient. Such technological evaluations are to be complemented by studies that attempt to understand human experience and use it for further improvements. Performing human experience exploration within ubiquitous computing environments is challenging for several reasons:

- Theoretically grounded design approaches for multi-device interactive environments that also incorporate everyday objects are still rare in the literature.
- Many system prototype designs are initiated and driven by the kind of devices and sensor/actuation technology available.
- Explorative system design processes like the easy ADL home design [2, 3] are influenced by many uncontrollable variables making it hard to conclude that a certain prototype implementation became better or worse than another due to the underlying design approach only.

Ubiquitous computing designers still have some way to go until standardized experiments can be used as a way to compare design approaches and outcomes. The work presented could be developed into a human experience exploration framework for ubiquitous computing in the future, useful for comparing results obtained in varying context, avoid reinventing the wheel and obtaining meaningful results. Note that the term human experience is used in this paper replacing the traditional human-computer interaction term "user experience" often used in related literature.

The goal of our human experience exploration is to get an initial empirical indication of to what extent a smart home that operates according to some of the principles of egocentric interaction would meet the needs and wishes of its occupants, and to use this result in further exploring the concepts surrounding egocentric interaction. The focus is on human experience rather than system efficiency or plain usability in a traditional sense. A smart home is not purely a computing system, and additional aspects like emotions, enjoyment, human affect, sensation, the meaning and value of human interactions, and aesthetic experience play an important role. According to ISO 9241-210: 2010 (clause 2.15), human experience (or user experience) is defined as "a person's perceptions and responses that result from the use or anticipated use of a product, system or service" [21].

### *A. Establishing the Experience Factors*

An important challenge is to select the appropriate and necessary experience factors to measure. The underlying motivation for performing the exploration is to let the scores provided by the subjects for individual experience factors validate the principles of egocentric interaction. Refer to Table 1. Additionally, the experience factors were inspired by heuristic evaluation [22] and an adapted version of it to ambient displays [23].

Since human experience changes over time, other factors like a human agent's earlier experiences, preconceptions and the current contextual conditions affect human experience making it subjective [24]. Table 1 presents qualitative measures that are quantized to make them comparable between subjects in different scenarios and useful for further analysis. Since human experience is dependent on the current context and varies at different points in time, it was evaluated both during (to a limited set of experience factors) and after the interactions within the smart home named the easy ADL home.

Momentary human experience is useful for understanding the subject's affect at a particular moment in time, while long-term human experience reveals the overall experience. For instance, experience factors that are influenced by the subject's immediate experience like visual perception load, audial perception load, motoric load and effectiveness of the peripheral notification techniques were self-reported by the subjects (talk aloud method) to a non-intervening observer who took notes during the related events. They were discussed afterwards during the interview session to obtain the scores for the individual factors ranging from 1 to 5.

Experience factors that are related to the subject's remembered experience like convenience in performing physical-virtual activities, wearability and ergonomics, aesthetics and pleasing design of smart objects (everyday objects embedded with ubiquitous computing technologies), agent control and uneven conditioning were self-reported after completing the scenarios by filling out a questionnaire. Imagined human experience based on anticipated use and user expectation was also evaluated. For instance, a human agent's anticipated experience in various social contexts within the easy ADL home like being alone, being with a partner, being with friends and being with family members were self-reported and discussed during the interview session. Imagined human experience of anticipated use is valuable especially since the easy ADL home is still in the development phase and could be made to accommodate or adjust for the scenarios imagined by the subjects as part of the remaining implementation process.

### *B. Scenario*

Three everyday home scenarios namely *weekday morning*, *weekday evening* and *weekend* were created and the subjects were asked to play out those scenarios, performing everyday activities in a natural manner. The question of how to perform the everyday activities were left to the subjects to answer themselves; however the subjects were asked to choose from 20 given activities for which the easy ADL home provides ubiquitous computing support.

For example, in the weekday morning scenario, subjects performed activities like preparing breakfast. An activity like preparing breakfast activates several applications like for instance the recipe provider and the old food detector. The easy ADL home uses the old food detector information to offer recipe choices for breakfast. Now the question is where to present information that will be effective for the subjects to choose an appropriate recipe and continue preparing breakfast without getting distracted. Here the egocentric interaction design principles come into play. Displays that are closer to human body and can be perceived are chosen for information presentation. But since a human agent is often mobile, proximal and situated displays are selected dynamically in real-time. In this case, if the subject is in the kitchen then the cutting board display and the refrigerator display are activated to present information. But when the subject moves to the dining hall, then the dining table display begins to continue presenting information. Similarly proximity is used for selecting the input device. Since wearable gesture bracelets and speech headset was used, selecting the appropriate input device was simplified. However, if those devices are not in the subject's action space, it means the subject is not wearing any input devices and the system urges the subject to wear an input device before they could provide explicit input to the easy ADL home. In the future when multiple distributed touch screens will be used for providing input to the easy ADL home, the role of action space will be more evident and relevant for selecting proximal input devices.

Where to present information also depends on the relationship between the information itself and its physical object association. For instance, a smart refrigerator presents information about the objects that it contains, the objects (or ingredients) that are getting old soon, etc. instead of information about books or music albums. Such a filtering aids in the pursuit of positive human experience instead of creating for instance cognitive overload when left unfiltered.

The easy ADL home has to make a decision on what information and services to offer and what to not offer at a particular moment in time. For example, while preparing breakfast, information about nutrition value, healthy eating, etc. and services like online shopping of cooking ingredients that are out of stock at home are more important than information concerning what to wear according to the weather information or online shopping of clothes. Here the activity context plays an important role in pruning information and services offered by the easy ADL home with the hope of improving human experience.

There was considerable noise during the enacted scenarios, especially while the subjects attempted to interact with the physical and the virtual aspects of the easy ADL home simultaneously. For instance, at times subjects spoke to another subject while at the same time attempting to manipulate a virtual object using speech. At other occasions subjects used their hands to perform normal everyday physical operations and in parallel attempted to manipulate a virtual object using gesture commands.

The subjects were allowed to perform parallel activities, with the possibilities of interruption and resumption of activities. Since everyday human activities usually involve mobility, the subjects were allowed to move around freely, resulting in physical objects, mediators and virtual objects entering and leaving the subject's situative spaces in a dynamic fashion. The activities were physical-virtual activities [9], i.e. activities that called for actions in both the physical world and in the virtual (digital) world. For example, the activity of "preparing breakfast" was performed using ubiquitous computing support and thus the activity ceases to be a purely traditional physical activity. Each subject performed at least five activities as part of the individual scenarios with some activities like "having dinner" or "watching a movie" also involving a second subject. In such situations only one subject received the computing support offered by the easy ADL home, while the other subject participated in a more traditional unassisted fashion. Before the subjects enacted scenarios, they were briefed about our work (not in detail that will affect the evaluation), the living laboratory home environment, the scenarios, what to do and what not to do. The subjects were wearing gesture bracelets and Bluetooth headset for manipulating the virtual objects, and a wireless access point on the chest. There was a system-training phase for adapting the laboratory environment to the subjects. The subjects trained a speech recognition engine (on an average took 12 minutes) and the gesture recognition engine (on an average took 10 minutes).

The subjects enacted the scenarios in two phases. During the first phase, the living laboratory home environment was similar to an ordinary home populated with purely physical objects. The subjects could access desktop applications through a laptop (based on the WIMP interaction paradigm) for obtaining activity support that was limited. Not all the applications that are useful within the easy ADL home are used during this initial phase. The subjects were not wearing gesture bracelets and the Bluetooth headset.

During the second phase, the easy ADL home was activated with physical and virtual objects co-existing in the living laboratory home environment. 19 mock-up applications were providing physical-virtual activity support to the human agent. For instance, the activity of "preparing breakfast" include some physical actions like preparing scrambled eggs, and some virtual actions like manipulating the "recipe provider" virtual object. Other applications include facilitating support for the activity of "dressing-up" where the weather information and the day schedule are used to provide suggestions for what to wear.

The subjects took approximately 3 to 4 hours to complete the two phases, to fill out the questionnaire and to attend the interview session. The experience measures were self-reported by the subjects due to the difficulty in obtaining corresponding physiological measures. Log files for evaluating some of the technical aspects of the easy ADL home were generated, however further details are beyond the scope of this paper.

### *C. Wizard-of-Oz Method*

Implementation of a fully functional smart home that fully adheres to the egocentric interaction principles will remain a challenge for some time to come. For instance, accurate sensing of the situative spaces [8, 4] is hard, even if sensor technology development certainly is making it increasingly possible. For the human experience exploration, a Wizard-of-Oz method was used to fill in the still missing (or not integrated) parts of the easy ADL home infrastructure. A Wizard-of-Oz software was implemented such that two experiment leaders (wizards) could provide information about a subject's situational context and activity context to the personal activity-centric middleware, something that is assumed to be possible to determine automatically with reliable accuracy in the future.

The first wizard was employed in indicating the subject's activity context by selecting one of the 20 activity contexts that were hard-coded into the software, including a "no activity" in case the subject is not performing any meaningful activity. A second wizard was employed in indicating the subject's situation as viewed through the situative space model. It was possible to hard-code into the system a fixed number of situations which included a certain number and type of objects in the various situative spaces for every situation due to: (1) nine smart objects in the easy ADL home were stationary with fixed physical location; (2) three wearable smart objects were always accessible to the human agent irrespective of their physical location since they were body worn; and (3) many of the plain objects in the easy ADL home like bed and sofa had fixed physical location. The subjects could move around freely within the home environment, and based on their location and orientation, the second wizard selected one of 32 possible physical situation options (the subjects could be in one of the 8 possible locations within the home and could be in one of the 4 possible directions namely north, east, south and west). The number of locations and directions were defined on beforehand based on the size of the home and its interior layout.


Fig. 2. A subject performing the physical-virtual activity of preparing breakfast where the cutting board smart object is used for cutting onions (i) and for accessing recipe information using speech and gestures (j).

The Wizard-of-Oz method introduces errors incurred by the wizards, but the two wizards (researchers) who ran the experiments were trained for the experimentation scenarios beforehand in order to minimize the errors when the actual experiments took place. There were latency delays (a few seconds in the worst case) that could occur occasionally due to the wireless infrastructure deployed in the home environment. Such short delays should have limited consequences in affecting the quality of a human agent's interaction within the easy ADL home, but the subjects were still briefed about it.

### *D. The Living Laboratory Home Environment*

The living laboratory home environment used for evaluation purposes in this study can be regarded as providing a relatively realistic experience for the subjects since it is an actual home enhanced with ubiquitous computing technologies. Also, it offers the possibilities to conduct controlled studies, often difficult in a real-world scenario and often important during the developmental stages. An informal workshop was conducted with 8 subjects (students of the interaction and design program at our university) aiming to understand the needs and wishes for support in everyday activities within the easy ADL home. The outcome of the workshop was the development of 19 mock-up applications that provides access to more than 100 virtual objects through the mediators. The majority of these virtual objects were designed to facilitate the execution of three variations of everyday home scenarios that were deliberately provocative explorations of what could potentially be possible and useful in the future, rather than minor extensions to common scenarios of today.

9 smart objects with interactive mediators and 42 smart objects with sensor motes were embedded into a 54 m2 apartment effectively forming a living laboratory [2, 3] complemented by three wearable mediator smart objects: two bracelets for hand gesture based virtual object manipulation and one Bluetooth wireless headset enabling speech based manipulation and audial perception. The 9 smart objects acted as multimodal mediators by being equipped with LCD displays (except the wall smart object where a projector was used) of varying dimensions for visual perception of virtual objects and a pair of audio speakers for audial perception. The interaction manager component that manages interaction based on egocentric interaction also made use of Microsoft Speech SDK 5.1 API for speech recognition of speech commands and for speech synthesis, and used a simple gesture recognition engine to discriminate among the hand gestures. Apart from the smart objects, more than 300 plain objects (i.e. physical objects without any mediators) were available in the living laboratory home environment to be used by the subjects when performing everyday activities.

### *E. Participants*

20 subjects (14 male and 6 female) not part of the research team took part in the human experience exploration with an average age of 28 years (minimum age was 18 years and the maximum age was 52 years). Even though the number of subjects used in this evaluation is limited making it difficult to generalize the results obtained, it is still a sizable total to get initial insights about human experience of the easy ADL home. The subjects were mostly affiliated with our university (student or employee), belonging to different departments including medicine, engineering and social sciences. The subjects were compensated with gifts worth around 50 SEK and some words of appreciation for their efforts. Since many of the subjects were involved with research within our university, they were enthusiastic and appreciated the research efforts in building the easy ADL home, but at the same time they tended to look at the solutions offered from a practical point of view.

### *F. UX Scores and their Value*

After enacting the three scenarios (both phase 1 and phase 2) mentioned earlier, each subject filled in the questionnaire form with scores between 1 and 5 for each question where the scores represent the human experience during phase 2 in comparison with their experience during phase 1. A score of 5 refers to very good (positive) experience during phase 2 in comparison to phase 1; similarly, a score of 4 refers to good experience during phase 2 in comparison to phase 1; a score of 3 refers to an experience equivalent during both phase 2 and phase 1; a score of 2 refers to bad experience during phase 2 in comparison to phase 1; and a score of 1 refers to a very bad experience during phase 2 in comparison to phase 1. Usually, if subjects provide a score of 3, then the central tendency bias might occur. In this case the subjects compare their experience with the easy ADL home and without it. By providing a score of 3, they agree to the nonexistence of a real difference between the two phases. Note that for experiences that are non-existing during phase 1, like for instance the match between the physical and the virtual characteristics of the smart objects since smart objects are not a part of phase 1 scenarios, the subjects provided a score that corresponds to their experience as being part of the easy ADL home since they have nothing to compare to.

The questions were intentionally non-technical and easy to comprehend. Example questions include "How convenient was it to perform the activities? Did you need to change your location often to access information? How easy was it to interact with the virtual objects? Would you like to live with your partner in this home? Were you able to complete the activities as expected? How appropriate are the smart objects in this home setup?" Some basic technical terms like virtual objects and smart objects were explained in simple language before asking them to fill in the questionnaire.

The number of subjects who answered the individual questions is presented in Table 1. Some questions (the momentary experience factors) were answered during the personal interview session where the subjects were free to provide their comments and clarify the notes made by the non-intervening observer while they were enacting the scenarios. This session removed some of the misconceptions that the subjects had especially in understanding the questionnaire that has resulted in a few scores that were modified by the subjects. The interview session was important in correlating the scores reported in the questionnaire to the subject's actual experience. The quantified scores in Table 1 would be of significantly less value without an interview session that clarified the reasons for the scores.

## IV. RESULTS AND DISCUSSION

Many subjects acknowledged the possible benefits of the easy ADL home in enhancing the everyday life of human beings in the future, especially the lifestyle of elderly and persons with disabilities. This is encouraging since one of the primary goals of this work is to explore and develop an interaction paradigm for ubiquitous computing environments that support everyday human activities.

### *A. Human Physical-Virtual Activities*

Providing support to human physical-virtual activities is an important feature of the easy ADL home. If one can say that there is good support for physical-virtual activities, it invariably means that interaction with both physical objects and virtual objects were supported well, by treating them equally, and the infrastructure made it easier to jump between the physical and virtual aspects of the smart home. If interaction with physical and virtual objects is not treated equally (in terms of sensing, modeling and facilitating interaction), then it is not possible/feasible to perform physical-virtual activities. Physical-virtual activities are performed by goal directed physical and virtual actions. By providing support for Physical-virtual activities, it also means that the easy ADL home was not just a shallow mixed-reality environment where physical objects and virtual objects are co-located. Physical and virtual events, actions, and activities are handled equally at a higher-level which is a step in integrating the physical and the virtual world. Hence physical-virtual equity is maintained throughout the design, implementation and exploration phases.

TABLE 1. Human experience scores for egocentric interaction design principles in the easy ADL home, also presented in a simplified form in our earlier publication [2] that focused on the physical-virtual equity principle.

| Human Experience Factors | Score (1 to 5) | No. of subjects that answered |
|---|---|---|
| **1. Human physical-virtual activities** | | |
| • Convenience in performing physical-virtual activities | 3.87 | 15 |
| • Seamless integration of virtual objects within those activities | 4.45 | 20 |
| • Efficiency in performing physical-virtual activities | 4.05 | 20 |
| **2. Human situatedness** | | |
| • Location change requirements to interact with virtual objects | 3.80 | 20 |
| • Useful and relevant presentation of virtual objects | 4.30 | 20 |
| • Human agent control in being part of the easy ADL home | 4.35 | 20 |
| • Uneven conditioning | 3.87 | 15 |
| **3. Human-centered load for interacting with virtual objects** | | |
| • Visual perception load in the easy ADL home | 4.32 | 19 |
| • Audial perception load in the easy ADL home | 4.79 | 19 |
| • Motoric load in the easy ADL home | 2.89 | 18 |
| • Cognitive load in the easy ADL home | 3.74 | 19 |
| • Wearability and ergonomics of the wearable unit | 2.00 | 20 |
| **4. Human attention** | | |
| • Unobtrusiveness of the virtual objects | 4.25 | 20 |
| • Effectiveness of the peripheral notification technique | 4.20 | 20 |
| • Sufficient virtual objects (not too many and not too few) | 4.18 | 17 |
| **5. Multimodal interaction with virtual objects** | | |
| • Intuitive usability of the interaction techniques | 3.65 | 20 |
| • Efficiency in accomplishing human initiated interaction tasks | 3.95 | 20 |
| • Synchronization among multiple modalities | 4.37 | 19 |
| • Easy transition to more in-depth information | 3.90 | 20 |
| • Visibility of all important states | 4.25 | 20 |
| **6. Social context** | | |
| • While being alone | 4.95 | 20 |
| • While with a partner | 3.30 | 20 |
| • While with friends | 3.05 | 20 |
| • While with family members | 2.90 | 20 |
| • While with a stranger | 2.90 | 20 |
| **7. Smart objects** | | |
| • Match between smart objects' physical and virtual characteristics | 4.05 | 20 |
| • Aesthetic and pleasing design of smart objects | 4.05 | 20 |

Egocentric interaction shares its part as well in looking towards an activity-centric interaction paradigm. Even though the focus has been on personal activities in this work, the long-term goal is to facilitate both personal and collaborative activities. Only 75% of the subjects reported their convenience in performing everyday activities within the easy ADL home. During the interview session it became clear that the significant amount of cables in the apartment, and the need to wear bracelet and headset smart objects made it difficult for them to express their convenience in performing activities. However, the subjects who did answer gave an average score of 3.87, indicating their positive experience in conveniently performing activities. Many of those subjects were also aware of the prototypical nature of the easy ADL home and were able to anticipate the potential convenience in performing activities in the future.

Treating human activities as first class objects and centering human interaction with virtual objects based on their activity context has yielded a score of 4.45 indicating very good human experience. Such an approach has also helped in bridging the physical and the virtual aspects of the easy ADL home since the human agents focus on their activities and not on whether an object is physical or virtual, as long as the object is useful in completing the current activity successfully. Taking an activity-centric approach has also enabled the subjects to perform physical-virtual activities with good efficiency yielding a score of 4.05. Activities within ubiquitous computing environments are likely to be physical-virtual [9] and having ubiquitous access to the virtual aspects improved the efficiency in performing those activities.

### *B. Human Situatedness and proximity to objects*

Human situatedness is an important principle of egocentric interaction, and the evaluation setup was designed to take the human agent's situational context into consideration, using the situative space model to ensure that only useful and relevant virtual objects were presented to the subjects within the different situative spaces and sets, yielding a very good experience score of 4.30. A mobile subject's relationship with environmental objects keeps changing dynamically. Even though the virtual objects are supposed to follow a moving subject, providing ubiquitous virtual object access, other contextual conditions, especially the availability of feasible mediators, affect the possibilities of ubiquitous access to virtual objects. The subjects" score of 3.80 for location change requirement in interacting with virtual objects indicates that the experience was good, but not very good. It is due to the dual nature of smart objects: in some instances they allow for the hijacking of its mediation resources for use by virtual objects that are not associated to those smart objects, while in other instances the smart objects allow only those virtual objects associated to it. However, introducing such a trade-off allowed for maintaining a reasonably good match between the smart objects" physical and virtual characteristics (score of 4.05).

Human mobility causes uneven conditioning [24]: the resources available in different human situations vary significantly. By considering a wearable approach (speech and gesture based manipulation of virtual objects using wearable headset and bracelet smart objects) to complement an augmented environment approach, a subject could interact with virtual objects even in situations without environmental mediators like on a lawn outside the house thereby masking uneven conditioning to some extent. A human agent's control of a situation is an important factor to consider in ubiquitous computing. Applications bombarding with virtual objects and services can take away a human agent's control of their current situation resulting in human agents bowing down to the situations created by the ambient intelligence applications. The mixed-initiative approach with separate interaction management rules for human-initiated and application-initiated modes of interaction proved rather successful: the subjects reported a very good feeling of being in command (score of 4.35).

### *C. Human-Centered Load during Interaction*

A human agent living as part of the easy ADL home might experience additional load on their visual perception, audial perception, motoric action, and other cognitive functions due to the inclusion of additional virtual objects and services. The easy ADL home is designed to make sure that such valuable resources of a human agent are not misused or over-used. Before the experience exploration, it was assumed that augmenting a physical environment with virtual objects and services would add to the visual and audial perception load for a human agent (since the subjects need to perceive both physical and virtual objects) compared to environments with only physical objects. Surprisingly, the subjects gave a user experience score of 4.32 for visual perception experience and 4.79 for audial perception experience. This suggests that virtual objects can successfully be co-located with physical objects within the easy ADL home and that the unobtrusive presentation of virtual objects even may be considered as an experience enhancer. This is similar to some of the augmented-reality research where the aim is to enhance the user-experience using digital technology. Also, suppressing aspects of the environment that are more of a noise, and can be augmented with valuable information. The situative space model (related to situatedness and the proximity principle) has an influence on the perception load (visual and audial) and the action load (using gesture and speech modality).

Evaluating a human agent's cognitive load as being part of the easy ADL home in comparison to being a part of an ordinary home environment is tricky since human cognitive load is influenced by a number of other factors. What is meant by cognitive load is how much the subjects had to think or keep in mind in order to interact with virtual objects within the ecology. The subjects gave a score of 3.74 for their cognitive load. During the interview session, the notes made for instance when a subject forgot the right speech command to manipulate a virtual object or when they were super efficient in performing certain activities involving a bit of thinking in manipulating physical and virtual objects (e.g. cooking) were discussed and influenced the final score of 3.74. During the interview session it also became clear that the reason they did not give a higher score was not that they felt that too much information was presented in the perception space that needed cognitive effort (which also fits the earlier mentioned score for visual and audial perception load). The reason was instead that it took some cognitive effort to recall the speech commands and the gesture commands (natural speech and gestures are not supported by the current prototype).

Motor load was given a score of 2.89, which indicates that additional efforts were required from the subject's perspective to perform gesture-based manipulation of virtual objects. Both speech and gesture techniques were welcomed by the subjects provided they were improved in the future. Interaction with virtual objects are highlighted in the study since virtual objects are presented and managed by the interaction manager component, while physical objects are already available in the smart home and are not much controlled.

*D. Human Attention*

Human attention is another important and scarce resource, especially within ubiquitous computing environments where interactions take place in real world context. This work has tried to investigate how it can be economized with a focus on peripheral attention. Human perception and action possibilities are related to human attention possibilities. The effectiveness of the proposed peripheral notification techniques using both visual and audial modality is indicated by a score of 4.20, and its unobtrusiveness in making use of the agent's attention (score of 4.25) is promising for further investigation in this direction. In ubiquitous computing, approaches that make proper use of a subject's peripheral attention are more likely to succeed compared to those seeking the agent's central attention all the time. Some subjects discussed about the different possibilities of presenting virtual objects so as to shift between peripheral and central attention, the most popular idea being to dynamically vary the visual objects" size. Only 17 subjects answered if there were sufficient virtual objects (not too many and not too few) within the different situative spaces to make optimal use of the subject's peripheral and central attention. This could be due to the rather abstract and complex nature of the question. However, those who answered were satisfied with the number of virtual objects within the situative spaces (score of 4.18).

*E. Multimodal Interaction with Virtual Objects*

The interaction manager is supposed to filter and select the right modalities for presenting information using egocentric interaction principles. Supporting multiple modalities for a human agent to interact within the easy ADL home was given high priority. It enables natural interaction in varied situations. Uneven conditioning due to the potential unavailability of appropriate mediators that could support a specific modality was masked to some extent since the virtual objects could be accessed and manipulated through several modalities depending on the contextual conditions including the availability of feasible mediators. It is important to make sure that the virtual object's state presented in different modalities within the easy ADL home is synchronized. Synchronization among multiple modalities (score of 4.37) was achieved by the centralized handling of virtual objects within the easy ADL home. Egocentric interaction does not choose between a centralized and a decentralized approach: both approaches have their pros and cons. Other usability factors like easy transition to more in-depth information, efficiency in accomplishing human-initiated interaction tasks and intuitive usability were considered and evaluated in different contextual conditions. A score of 4.05 for efficiency in accomplishing human-initiated interaction tasks indicate that the mixed-initiative approach and the handling of the virtual objects through two types of interaction sessions (human-initiated interaction sessions and application-initiated interaction sessions) were yielding good user experience. The subjects can perform human-initiated tasks while in parallel benefitting from application-initiated virtual objects.

*F. Social Context*

Social context is intended to be included in the future versions of the situative space model that will include human agents within its spaces. It is important to know the initial reaction. Human beings in general are social animals and ubiquitous computing environments might include more than one human agent. The work reported here have chosen to focus on the case of a single human agent before proceeding to investigate the case of supporting multiple human agents in parallel. As part of the preparations to extend the approach to multi-agent environments, the subjects were asked to imagine themselves being part of various social circumstances. Several issues were discussed including the roles of individuals in a social context and the possibilities to share resources. The subjects experienced the initial attempts in addressing privacy of virtual objects within the easy ADL home and the scores were not just a mere speculation but a result of experiencing privacy issues and other related issues. Most subjects felt that they would have a very good experience if they were alone (score of 4.95), which is not very surprising since the three scenarios were designed for giving support to only one subject at a time (even though some scenarios were enacted by two subjects in parallel).

The subjects were doubtful if they would want to be in the smart home while being with a stranger (score of 2.90): privacy, trust and many other factors come into play. Surprisingly, the subjects were also reluctant to be in a ubiquitous computing environment while being with family members (score of 2.90), and friends (score of 3.05). The subjects expressed a need to socialize with people rather than interacting with computers even though they acknowledged that the computers within the easy ADL home were not like computers in the traditional sense. A deeper analysis might show that, again, the scenarios and the support provided by the applications were for single human activities. Scenarios where collaborative activities are performed by family members or friends could have changed the experience scores and is an interesting future work to do. The modeling of the easy ADL home based on egocentric interaction does not restrict the support to be given to a single human agent since multiple situative spaces for individual human agents within the easy ADL home could be developed and investigated in the future. However, multi-agent environments raise a number of additional issues. A simple case where two human agents are concerned with their own personal activities might introduce disturbances, conflicts and resource sharing issues that a support system could detect and help to avoid or alleviate. There might actually also be support for serendipitous, ad-hoc cooperation. It is conceivable that the subjects would have had a less skeptical view with regard to the social issues if the ubiquitous computing environment had exemplified support for collaborative activities.

### G. Design of Smart Objects

The design of smart objects targeted to be a part of the easy ADL home is a major challenge. Congruence between smart objects' physical and virtual characteristics is considered to be an important design principle. For instance, a bathroom smart object should not present food recipes (virtual object) in the bathroom as they are bad places for cooking, preparing a food shopping list, or almost any activity associated with the process of cooking food. The congruence principle disallows smart objects to be one-device-for-many purposes like the typical desktop computer. An equally weighty but conflicting design principle is that virtual objects should not be device-centric: the virtual objects in general are expected to be able to move freely and not be stuck in some particular physical object at a particular physical location. The conflict between these two design principles results in what is referred to as the dual nature of smart objects and a requirement for a proper trade-off in the design that allows both principles to exercise influence in parallel. The subjects have answered for the experience factor of match between smart objects' physical and virtual characteristics with a score of 4.05 acknowledging the design decision to yield good experience.

Smart objects are not just devices providing functionality but should be integral parts of a human environment, so they need to be designed in an aesthetically pleasing fashion. The subjects were impressed with some of the smart objects, especially the dining table smart object and the bathroom mirror smart object, and gave an overall score of 4.05 for aesthetic and pleasing design of the smart objects. Two subjects asked us if some of the smart objects could be designed for their home. Inspired by heuristic evaluation [23] on ambient displays, the aesthetics and pleasing design was given equal importance to their functionality while designing the smart objects.

### H. Additional Remarks by the Subjects

The interview session was important to clarify the emotions and the enjoyment that the subjects had when being part of the easy ADL home. 16 of the subjects enjoyed being a part of the smart home, with enthusiastic emotions and hopeful expectations on the future. The remaining 4 subjects were more cautious in expressing their feelings. The subjects' willingness to live in the easy ADL home has a lot to do with their social context. Wearability and ergonomics were a major concern for the subjects with a score of 2.0 since wearing the currently quite ergonomically intrusive objects while sleeping, taking a shower and dressing are hard to imagine at least in the near future.

## V. Conclusion

This paper described egocentric interaction as a post-WIMP interaction paradigm for ubiquitous computing. A smart home built on the principles of egocentric interaction was used for a human experience exploration where key principles like proximity and situatedness, and physical-virtual equity have yielded promising scores to continue further work on exploring the situative spaces and to include relationships between objects within it in the future. While the study itself is an initial attempt in evaluating the egocentric interaction principles, it is an important step forward for exploring future development of human-centered spatial models of interaction for ubiquitous computing.

## References


[1] M. Weiser, "The computer for the 21st century", Morgan Kaufmann Publishers Inc. San Francisco, USA, 1995.

[2] D. Surie, T. Pederson, L-E. Janlert, "The easy ADL home: A physical-virtual approach to domestic living", Journal of Ambient Intelligence and Smart Environments, Smart Home Thematic Issue, IOS Press, vol. 2, issue 3, 2010, pp. 287-310.

[3] D. Surie, L-E. Janlert, T. Pederson, D. Roy, "Egocentric interaction as a tool for designing ambient ecologies – The case of the easy ADL ecology", Journal of Pervasive and Mobile Computing, Special Issue on Ambient Ecologies, Elsevier, 2012.

[4] D. Surie, F. Jäckel, L-E. Janlert, T. Pederson, "Situative Space Tracking within Smart Environments", Proc. of the Sixth International Conference on Intelligent Environments, IEEE Computer Society, 2010.

[5] D. Surie, O. Laguionie, T. Pederson, "Wireless sensor networking of everyday objects in a smart home environment", Fourth International Conference on Intelligent Sensors, Sensor Networks and Information Processing, 2008, pp. 189-194.

[6] T. Pederson, L-E. Janlert, D. Surie, "Towards a model for egocentric interaction with physical and virtual objects", Proc. of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, ACM, 2010.

[7] A. Dey, "Understanding and Using Context", Journal of Personal and Ubiquitous Computing, vol. 5, 2001, pp. 4-7.

[8] T. Pederson, L-E. Janlert, D. Surie, "A Situative Space Model for Mobile Mixed-Reality Computing", IEEE Pervasive Computing, 2011.

[9] T. Pederson, "From Conceptual Links to Causal Relations PhysicalVirtual Artefacts in Mixed-Reality Space", Doctoral report UMINF-03.14, Umeå University, 2003.

[10] D. Surie, T. Pederson, F. Lagriffoul, L-E. Janlert, D. Sjölie, "Activity Recognition Using an Egocentric Perspective of Everyday Objects", Ubiquitous Intelligence and Computing, Springer LNCS, 2007.

[11] H. Ishii, The tangible user interface and its evolution", ACM Communications, vol. 51, 2008, pp. 32-36.

[12] P. Dourish, "Where the Action Is: The Foundations of Embodied Interaction", The MIT Press, 2001.

[13] S. Benford, L. Fahlén, "A Spatial Model of Interaction in Large Virtual Environments", Proc. Of the Third European Conference on Computer Supported Cooperative Work, Kluwer Academic Publishers, 1993, pp.109-124.

[14] A. Ferscha, M. Hechinger, R. Mayrhofer, M. dos Santos Rocha, M. Franz, R. Oberhauser, "Digital Aura", 2nd International Conference on Pervasive Computing, Austrian Computer Society, Vol. 176, 2004, pp. 405-410.

[15] S. W. Loke, S. Ling, M. Indrawan, E. Leung, "Q-Aura: a Quantitative Model for Managing Mutual Awareness of Smart Social Artifacts", IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans, vol. 41(1), 2011, pp. 161-168.

[16] G. Kortuem, C. Kray, H. Gellersen, "Sensing and visualizing spatial relations of mobile devices", Proc. of ACM symposium on User interface software and technology, ACM, 2005, pp. 93-102.

[17] J. P. Souza, D. Garlan, "Aura: an Architectural Framework for User Mobility in Ubiquitous Computing Environments", IEEE/IFIP Conference on Software Architecture, Kluwer Academic Publishers, 2002, pp. 29-43.

[18] N. Sawhney, C. Schmandt, "Nomadic radio: speech and audio interaction for contextual messaging in nomadic environments", ACM Transactions on Computer-Human Interaction, 2000, pp. 353-383.

[19] S. Greenberg, N. Marquardt, T. Ballendat, R. Diaz-Marino, M. Wang, "Proxemic Interactions: The New Ubicomp?" ACM Interactions, vol. 18(1), 2011, pp. 42-50.

[20] E. T. Hall, "*The Hidden Dimension",* Doubleday, New York, 1966.

[21] A. Vermeeren, E. Law, V. Roto, M. Obrist, J. Hoonhout, K. Väänänen-Vainio-Mattila, "User experience evaluation methods: current state and development needs", Proc. of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries, ACM, 2010.

[22] J. Nielsen, R. Molich, "Heuristic evaluation of user interfaces", Proceedings of the SIGCHI conference on Human factors in computing systems: Empowering people, Seattle, United States, ACM, 1990.

[23] J. Mankoff, A. Dey, G. Hsieh, J. Kientz, S. Lederer, M. Ames, "Heuristic evaluation of ambient displays", Proc. of the SIGCHI conference on Human factors in computing systems, ACM, 2003.

[24] E. Law, V. Roto, M. Hassenzahl, A. Vermeeren, J. Kort, "Understanding, scoping and defining user experience: a survey approach", Proc. of the 27th international conference on Human factors in computing systems, Boston, USA, ACM, 2009.

[25] M Satyanarayanan, "Pervasive Computing: Vision and Challenges", Personal Communications, IEEE, vol. 8, 2001, pp. 10-17.