An Approach to Mixed Initiative Control of Adaptive Multimedia Environments

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Abstract

This paper describes an approach for accessing Ambient Intelligence Environments (AmI-E) based on mixed-initiative interaction. Our approach combines mobile interaction appliances with situation-aware interaction. By doing so, we address some major challenges of Human-Environment-Interaction such as *loss of user control*, *missing system image* or *over-automation*. Significant contributions are mechanisms and metaphors for interaction management which avoid and solve conflicts between the user initiated interaction and the actions performed by the adaptive environment. Especially, we describe a generic interaction model and an architecture for mixed-initiative environment control.

Within this paper we first analyze the challenges of existing interaction approaches and argue for a mixed-initiative approach to overcome identified challenges. We provide a novel interaction model and describe a prototype realizing this approach.

Ambient Interaction and Motivation for a Mixed-Initiative Approach

Considering the vision of Ambient Intelligence (AmI) our everyday environment and its objects will be pervaded by sensing, computing and communication capabilities. A major characteristic of such environments is the *increasing amount* of intelligent devices and their *complexity*; Computers will be ubiquitous. As household appliances grow in complexity and sophistication, they become harder and harder to use, particularly because of their tiny display screens and limited keyboards [16].

At the same time devices will *disappear* into the background and will be *invisible* to the user. With the emergence of newly available technology, the challenge to maintain control increases, while the additional value decreases. After taking a closer look at Ambient Intelligence environments (AmI-E), there will come up the (general) question of how to build a more intuitive way for people to interact with such an environment.

Within the next chapters, we discuss such challenges of interacting with complex, disappearing, and adaptive environments (e.g., such as AmI-E). We will discuss existing research analyzing some important challenges of Human-Environment-Interaction. Based on this discussion, we will show major advantages and weaknesses of explicit interaction vs. implicit interaction. As a result we will motivate to follow a mixed-initiative approach to interact with Ambient Intelligence environments. In the second chapter, we will present an interaction model designed to overcome identified interaction challenges.

We argue that our approach increase user control over adaptive environments. This is achieved by using a mobile assistant which provides intuitive and explicit access to AmI-E thus allowing always the user to stay in control. Another benefit is that using intuitive metaphors and *conflict management mechanisms*, the user can define and restrict the behavior of the implicit actions initiated by the AmI-E. This allows the user to avoid, stop, or undo inappropriate adaptivity which will increase the reliability of the overall system. Allowing the user to remain control and increasing the reliability of the AmI-E will increase trust in automated system thus motivating the user to accept and use the technology.

Challenges of Interacting with AmI-E

A variety of research works deal with interacting within intelligent environments and its specific challenges:

Complexity of the Environment

When interacting with AmI-E, users are overloaded because of the huge amount of networked appliances and their increasing functional complexity [10]. How to interact with all those devices? It is difficult for the user to identify and activate the right device or service to perform a specific task on it [6]. Existing user interfaces are difficult to use since they require a device address for device activation purposes which is actually very difficult to remember.

Invisible or Tiny User Interfaces

Users fail to develop an adequate mental concept for the AmI-E and its interaction concept. The reasons for this are the integration of the infrastructure into the background and the missing or invisible user interfaces. Especially small everyday appliances such as pens, caps, tables or shoos do not provide appropriate user interfaces.

To overcome these both challenges, new interaction models are required [3]. Some research questions can be derived from the above mentioned points which are important to develop an intuitive interaction model.
One question is how to interact with tiny devices that do not provide their own user interfaces? How to find and access devices in an environment which are invisible to the user? How to access physical devices in an unfamiliar environment without having knowledge about the technical infrastructure such as device addresses and IP-numbers?

Rehman et al [11] provide a good overview of existing interaction systems. Another overview is given by E. Aarts & J.L. Encarnação (2006) which is recently published in [2]. Therefore, we avoid to describe particular systems at this point. Moreover, we will outline challenges within the next chapter which are common to particular classes of Human-Environment-Interaction.

Existing Approaches for Human-Environment-Interaction

Following a classification model for Human-Environment-Interaction presented by A. Dey et al (2001) [3], an interaction can be explicit, implicit, or mixed. But in general, Human-Environment-Interaction is divided in two classes: explicit and implicit interaction. Within the scope of an explicit interaction the user can decide when to perform which activity. In contrast to the explicit interaction approach, by an implicit interaction actions can also be performed automatically. In such a case the environment takes the initiative to perform an activity. The user does not determine directly when what happens. Instead, users are observed to *understand* their current behavior and situations.

Challenges of Implicit Interaction

When analyzing the implicit interaction approach some major challenge comes up. It is the *lack of control* and *Over-automation*. Several works reported already that people do not accept a full-adaptive and 'over-automated' environment [11]. Instead, users should always be in control [2]. Some other important challenges are described in the following paragraphs.

Lack of Visibility and Predictability. Another challenge of implicit interaction – when deploying it for complex ubiquitous environments – is 'the lack of system faces' [6, 11] in full-automated environments. This makes it difficult for users to build an appropriate mental model about the system [11] and to understand the automated (re)actions of their intelligent environment (*visibility* & *predictability*). One component in the successful use of automated systems is the extent to which people trust the automation to perform effectively. In order to constitute trust in automated systems users need to understand the current system's state ('visibility') and to predict its behavior [4, 8]. Thus, an adequate representation of the system is required to support the development of user's mental models as well as his trust in the automated system.

Overriding the default bahaviour not possible. Another challenge is the missing ability of users to override the default behavior of the system. Beside these challenges, rich input from environment is necessary for truly intelligent (i.e. meaningful and appropriate) behavior. This requires highly-developed context-awareness techniques (models, sensing technologies, reasoning . . .) which is one of the current challenges of Ambient Intelligence.

Challenges of Explicit Interaction

The challenges of an implicit interaction (lack of control, over-automation, missing system face, less developed context and situation awareness) can be bypassed when following an explicit approach. Instead, other challenges appear: the lack of intuitive device selection.

There are many approaches for explicit interaction, e.g. voice-based interaction or user interfaces based on Augmented Reality. However, a common challenge of this kind of interaction systems is the lack of intuitive device selection in unknown environments. Following an explicit interaction approach, the user determines what happens when. In order to do this, one can use an assistant system. Since the user is in charge of activating devices and functions he has first to select them manually. In most of the existing user interfaces devices have to be identified and selected based on 2D-icons, complex menus, or device numbers. It is truly a big challenge to find and activate needed devices [6]; especially in foreign and complex environments and without having technical background knowledge such as a device URL.

Even natural gesture-based interactions does not solve this problem since one can not easily point to a device which is seamlessly integrated into the environment. Or how to point to a tiny device which is at the other end of a big conference room?

Within the next chapter, we will introduce a novel interaction approach to overcome the problem of intuitive device selection in unknown environment. The interaction model is based on the well-known idea of mixed-initiative interaction. However, it assumes that the implicit interaction part is done by the adaptive Ambient Intelligence environment. The mobile and personal interaction appliance of the user provides the explicit interaction part. Since *interaction conflicts* can happen, the mobile user interface provides also required mechanisms and metaphors for *conflict management*.

Hybrid Interaction: A Generic Interaction Model for Human-Environment-Interaction

A mixed-initiative interaction model can overcome the weaknesses of both implicit and explicit interaction. Following this, Human-Environment-Interaction should consist of a combination of both implicit and explicit interaction to overcome above-mentioned challenges. In addition to a function-oriented environment control based on a mixed-initiative interaction model, the assistant system also allows for a goal-based interaction [5]. By doing so, the user will be able to express goals which will be achieved by the environment. This is why we use the term of *hybrid interaction* instead of the uni-dimensional term of mixed-initiative interaction.

Such a hybrid interaction provides both explicit and implicit access to Ambient Intelligence Environments (AmI-E) at the same time. By doing so, the user can for example use an explicit assistant to interact with adaptive environments. For example, within a presentation scenario in a smart lecture room, the adaptive environment could provide some adaptivity such as reactive interaction with air conditioning and lighting devices while the user could use the explicit remote control assistants to manage the presentation. Due the concurrent nature of this mixed-initiative approach, interaction conflicts can exist. Here, an important issue is the conflict resolution and interaction synchronization of concurrent environment control at a semantical level. It should be avoided that an implicit interaction system can perform activities which would effect the environment in a opposite manner as intended by the user when he had recently interacted with his environment using an explicit assistance system. The major scientific challenge is to handle arising conflicts, opposed actions, or inappropriate automatisms of the adaptive environment.

Benefits of a Hybrid Interaction

The overall approach of a hybrid interaction is shown in figure 1. It combines the benefits of implicit and explicit interaction. At the one hand, this will allow the user to "'stay in the loop"' because there is always the possibility to access the environment via the explicit assistant system. At the other hand, the user is supported by the implicit system. The benefits of automation remain. The problem of an over-automation would not exist any more, because the user will be able to decide which activities are permitted for an implicit interaction. Inappropriate pro-activities can be reversed using the explicit assistant thus the usability of the system will increase.

One challenge still remains. It is the problem of manual/explicit device selection and the complex nature of existing user interfaces for environment controller assistants. To overcome this, we propose to deploy 3D metaphors for device selection and access. The AMCO system follows this approach. Its architecture and user interface is described in detail in [13].

When users express goals to interact with their environment, they do not care which specific devices and operations to choose in order to achieve the goal. Instead, this is done by the system. The environment will determine the strategy (set of functions) to achieve the goal and will also assign those functions to available devices. Therefore, goal-based interaction protects users from the complexity of their environments. However, users must also be able to interact based on specific functions and devices. This is because of the mental model of the users. Most of them think in terms of functions and therefore prefer a function-based interaction. Only when the technology becomes *fully* invisible – which is implausible – they begin to express goals instead of functions [12].

Through the hybrid interaction the usability of the system improves because mistakes of the implicit system can be corrected by using the explicit interaction.

Behind this, the implicit and explicit interaction will be coordinated and synchronized thus conflicts can be avoided. The user can regulate the grade of automation and he can correct "'wrong automatisms"' or inappropriate adapation of the environment. This increases user's trust because the user can retain the control of his environment. An assistant system provides a face for the AmI-E which helps the user to build an adequate mental model for the AmI-E. Using 3D user interface users can select devices without having technical information about the environment such as device addresses. It means less cognitive effort for exploring and accessing complex an dynamic AmI-E.

Specific Problems and Scientific Question

After having a detailed look into the presented general interaction model, one can identify several questions. A challenging issue is to find metaphors and strategies for interaction management. How can the system notify about activities which are happening outside user's interaction focus and attention's foreground? How can the user be notified about conflicting interactions initiated by the intelligent environment?
The challenging fact here is to design an interaction system for controlling AmI-E because of the distributed nature of the environment's devices. Since not all of the devices are located within the user's view, the implicit input and output is distributed through space, time and user's attention. However, independent of user awareness, most of the modifications to the environment may affect the user in an indirect way since s/he is living in the same world which is controlled by the system thus s/he will experience modifications to the environmental parameters such as noise, illumination, temperature and will also see some device modifications such as blind movement, ventilator movement, modifications to display and other output devices.
Here, the user is *naturally* noticed about the shutter control. However, he may not be noticed about the implicit modification of *invisible* device: those that are integrated into the background of the room or are outside of the user's attention (cf. fig. 2). Even if some automatic actions (e.g., automatic control of blind shutters and heater device) may happen in the background but their effect may affect the user. Moreover, they can disturb the user in some situations.
Imagine a presentation scenario where the user is focused on his slides rendered on the main screen of the room. Imagine the intelligent environment reacts to a situation and executes a rule which moves up the room's blind shutters and opens a heater device; both executed as one transaction. Both devices may be located outside the users activity focus and also not co-located with the user. However, opening the shutters may influence the illumination thus creating an inappropriate presentation setup. Therefore, the user needs some appropriate mechanisms to stop or undo such an implicit interaction.

Since the interaction is distributed over time, space, as well as the user's attention area it is difficult to apply well known metaphors from the desktop world [] to our domain. The

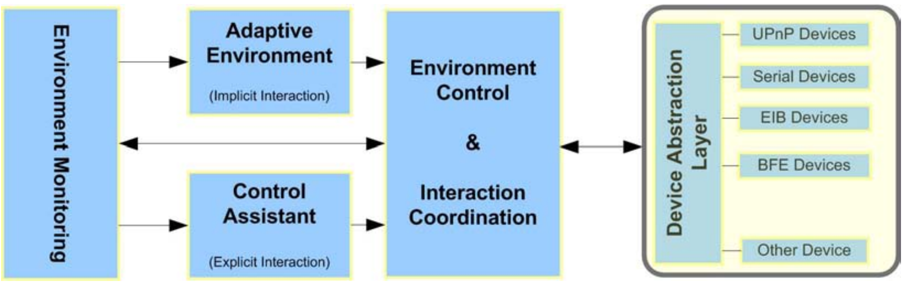

Figure 1. Overall approach of the AMCO system [13] is to provide a hybrid interaction through combination of explicit 3D-based assistant and adaptive environment. It allows for explicit interaction with the environment using a mobile controller assistant.

Figure 2. A AMCO prototype used for a lecture room of the Fraunhofer IGD

problem is to determine whether the user wants to undo the complete transaction or just the shutter movement. Is s/he disturbed because of the temperature change, the illumination change or because of the noisy movement of the shutter? For the latter case, a conflict resolving means to stop the shutter and not to move the shutter down in order to darken the room. For the first case one could close the heater and open the windows.
Another important question is to define the semantic of the undo operation. In some situation it means to perform an action with opposite effect to the environment which will lead into the desired state. For example opening windows and turning on a ventilator as an undo operation to "opening the heater" in our example scenario. In some other situations, the undo operation means to stop a running activity such as stopping the moving down shutters from our previous example.

The scientific point here is to provide the user intuitive and effective conflict management elements and create an awareness for their existence in such a way that the user can use those mechanisms to solve conflicting interactions.

Within the next chapters we describe such mechanisms and an adequate architecture which can support a mixed-initiative with the described interaction management features.

A Prototype Realization

The Ambient Controller (AMCo) is a novel Control Point which provides integrated and intuitive access to the user's surrounding and media repositories [13]. It allows to control and manage intelligent environments.

AMCo follows a hybrid interaction model as described in the previous chapter. It provides an explicit environment control and mechanisms for interaction synchronization and conflict management (see fig. 2). It provides both function-based interaction and goal based interaction. By doing so, the user will be able to express goals which will be achieved by the environment. User express their goals by selecting macros. A macro contains the strategy to achieve the desired goal. Our approach for goal-based interaction is published by Encarnação et al in [2] and will not be discussed in this paper. Moreover, within this paper we focus on mixed-initiative aspects of the interaction model and the architecture as well as metaphors for conflict management.

AMCo addresses the problem of manual device selection and the complex nature of existing user interfaces for environment controller assistants. To overcome this, AMCo deploys 3D metaphors for device selection and access (see fig. 2). At the one hand, it allows for a direct device access. At the other hand, it provides macros which dynamically consider new devices by using plug and play and device discovery mechanisms.

AMCo uses an automatically created 3D visualization of the environment. Entering a room, it discovers the infrastructure and available devices and builds the integrated user interface.

The 3D visualization creates a logical link between physical

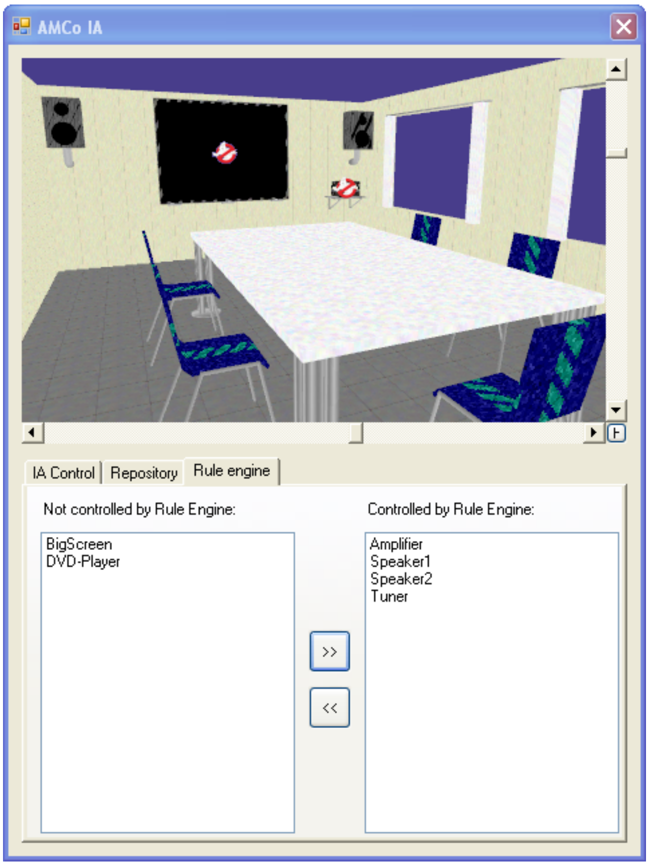

Figure 3. s

devices and their virtual representation on the user's PDA. By doing so, the user can easily identify a device within his environment based on its position, orientation and form. There he can access the identified devices through the 3D interface and manipulate them directly within the scene. For example he can click on a 3D object to turn on a light. The 3D interface allows the user to access the infrastructure without demanding knowledge about specific device names, IP-numbers, URLs etc. Changes to the environment, new devices or re-positioned devices are identified and implicate an update of the UI. Henceforth, the user can access identified devices through the 3D interface and directly manipulate them. For example, he can just click on a 3D object to turn on a light.

Figure 2 shows the user interface of the AMCo system.

The WIMP-based 2D interface of AMCo provides document access. The user is able to transfer objects from his 2D world to his 3D world. By doing so, AMCo integrates the virtual media repository as well as the physical environment of the user into a unified personal environment. This enables the user for example to move a PowerPoint document – which is stored on his notebook – to the projector by just one drag&drop operation. For both 3D and 2D interaction, AMCo provides unified metaphors (pointing, selecting, drag&drop, clicking) so the user can handle projectors and lights in the same manner he also interacts with his files and directories. By doing so, we extend the well-known metaphor of direct manipulation to the physical world.

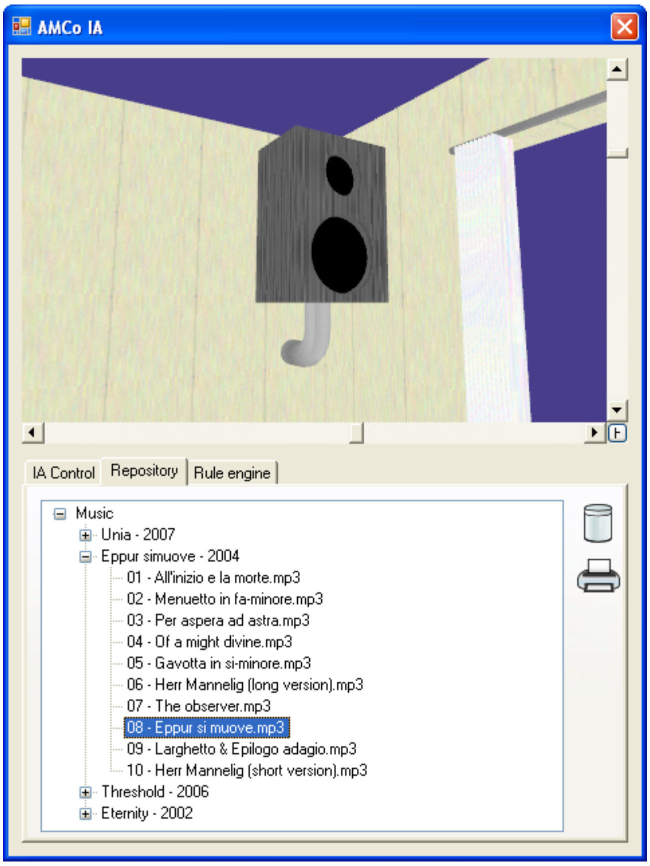

Figure 4. s2

Our design preserves as much consistency as possible in the metaphors and GUI aspects of the interaction, so that our application have similar look and feel like the applications from the desktop world.

We used the Intel UPnP stack as a basis middleware for our system. For example, a device discovery feature is required for dynamic creation of the 3D visualization of an environment. The UPnP technology provides such a device discovery. However, we made some extensions to it in order to make it location-aware [15]. Deploying the UPnP technology brings the following benefits:

- Device Discovery: entering an environment the 3D scene of the raw room (without devices) is downloaded from a known database. Next, the system discovers available devices and inserts their corresponding 3D counterpart within the 3D scene at the right position and orientation [13],
- Media Management: Our system uses the UPnP A/V architecture in order to provide access to media on several devices,
- Standardized Device Access: UPnP allows to access devices of various environments by a standard protocoll. This allows to control foreign environments.

Some aspects of the AMCo user interface, the Location-Aware UPnP Presentation Architecture, as well as the dynamic 3D creation for a new environment are described in detail in [13] and [15].

Beside UPnP, AMCo also requires position and orientation information, which we gather by geometry management system, using a combination of the Ubisense [7] system for positioning persons. We developed a passive RFID based system [14] to gather precise orientation and position information for mobile multimedia devices. Stationary devices such as fixed back projection systems provide their location information by their self. For this purpose, we extend the UPnP device profile. For each (UPnP) discovered device we look up its position and orientation and disclose devices located in other rooms of the same sub-network (UPnP discovery delivers every UPnP device of a subnet). We extend each UPnP device by an UPnP service (optional; not part of the standard) providing dynamic location information for that device. We deployed this design architecture to all real life meeting and conference rooms at Fraunhofer-IGD (Darmstadt, Germany).

Related Work

At a general level, [1, 9] have a major impact of the current paper because they sketch the basic ideas of Ambient Intelligence and intelligent environments and the characteristics of AmI-E. The investigation of these information lead to the general question of the current work.

At a detail level, the current work is based on prior research within the field of ambient interaction. A comprehensive study on mental models for future home environments [12] investigates the approach of goal-based interaction with disappearing computers. They show in which situations the users tend to interact by means of explicit function-based commands and when they accept an automation. The results of [12] confirm with the hypothesis of this paper that a full-automated system is not accepted by the users; instead a complementary explicit interaction should be available.

Rehman et al. [11] as well as Lindenberg et al. [6] report the problems people are faced when interacting with such environments. Also these two works are confirming before mentioned challenges of "‘interfacing with the invisible computer"’ and implied requirements for an intuitive interaction model which have been identified by the first chapter of this paper. Especially, they underline the problems of ‘over-automation’, ‘Loss of Control’, complexity of the environment and lack of appropriate user interfaces on smart everyday devices.

Rehman et al. [11] propose an Augmented Reality (AR) based interaction concept to overcome the above mentioned problems. Behind this, the AR approach to access physical devices is not appropriate for large environments because it only recognizes devices which are within the capturing zone of the camera. In contrast to [11], we provide a 3D-based interface which overcomes those weaknesses. The user can even explore larger environments using the 3D-scene. The ‘camera view’ can be automatically moved to a certain part of the 3D-scene depending on the current user situation, i.e. user position and orientation, current activity and environment context. This is not possible with AR. Another drawback of AR systems is the additional HMD which is necessary to interact. It is difficult to make input / to manipulate 3D objects using AR input devices or even natural gesture. In comparison, it is easier to use for example a PDA and a stylus to make input.

Lindenberg et al. [6] provide an approach for natural-language based device selection. Generally, this approach can be used to overcome the problem of device selection (has been described in section) and to identify and select the right device without requiring knowledge of technical infrastructure information (e.g. device URLs). However, speech interaction is not appropriate for many domains. For example, when presenting your PhD thesis you do not want to speak to the projector. The speech and gesture modalities are already busy because they are used for Human-Human-Interaction; e.g., to explain the slides. Moreover, robust speech recognition in public spaces for multiple users is another challenge of speech and gesture interaction.

The related work [6, 11, 16] do not discuss at all how to allow an explicit assistant system to *coexist* with an implicit adaptive environment. They either follow the implicit or the explicit paradigm. Thus the benefits of a combination are not considered. In contrast to them, we introduce a novel interaction model based on coexisting explicit and implicit interaction components. Our explicit system is based on a 3D user interface which overcomes the problems of intuitive device matching in complex environments.

The interaction challenges discussed in section is partially the focus of current research within the field of Ambient Intelligence. Several research works are currently investigating similar aspects of our research questions:

- goal-based explicit interaction with the environment [16]
- tangible user interfaces
- Augmented Reality and wearable computing [11]
- natural language interfaces [6] and gesture-based interaction

However, the above alternative approaches do not solve (completely) the interaction challenges we discussed within the chapter (e.g., over-automation, inappropriate pro-activities, complexity of the environment and device selection). Currently, there is no work known to the authors of this work which is investigating a hybrid approach to Human-Environment-Interaction. Although, the approach of 3D based dynamic user interface for explicit environment control assistants is new.

The Evaluation

The evaluation of AMCo has been done by a quantitative usability test and a complementary qualitative analysis of the software ergonomics based on ISO 9241/10 standard.

Within the scope of the quantitative usability test, the task completion time and the rate of errors have been analyzed. For this reason the test users have used two interaction systems to perform tasks. This allowed us to compare the usability of the mobile 3D-based AMCo system against a stationary central control panel (CCP) which is based on traditional menus and icon-based metaphors (see figure 5).

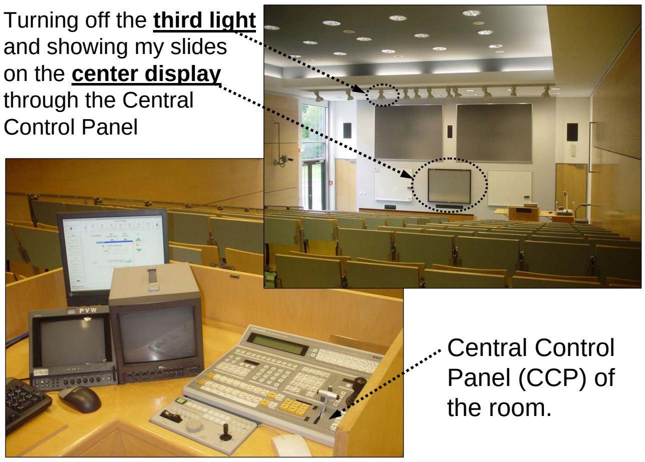

Figure 5. Challenges of Human-Environment-Interaction and the complex structure of existing control systems (the CCP shown on the bottom left)

The user evaluation test has been performed in a traditional meeting room. The persons conducting the evaluation were both trustworthy and competent to perform the evaluation, so that the evaluation results maximum credibility and acceptance. The usability test analysed most important activities of a presentation scenario. We selected the test situations and the activities involved with them from a situation-concept and a hierarchical task model for presentation scenarios.

A total of 46 subjects performed 41 different test cases (e.g., "‘set up the room for a presentation!"’ or "‘present your thesis-slides on the back-projection system!"’). Some activities have also been performed using manual controls (e.g. light switch). Before performing an activity, we prepared the room and re-started the interaction systems. Each subject has been introduced to both of the control systems. We avoided to have several test users at the same time in the room. During the inquiry, it became obvious that a verbal explanation at the beginning was desirable and could have positive consequences on further motivation. The results of the quantitative usability test have been already published elsewhere. In this paper we focus on the qualitative usability test analysis.

The qualitative usability analysis scrutinised the Perceived Ease of Use (PEU) and the Perceived Usefulness (PU) of the AMCo system from the point of view of end users. In order to analyze the PEU and PU, end users were requested to answer related sets of questions. For data collection, specifically designed questionnaires were given to end users of the AMCo system, just after performing the quantitative usability test (task completion time and error rate). We have used ISO-Norm 9241/10 questionnaire, which was derived from the software ergonomic standard DIN EN ISO 9241, Part 10 (German Industry Standard). ISO-Norm 9241/10 Usability is a group of norms that allows evaluating the capacity of an interactive system to offer to his/her user the possibility to accomplish tasks in an effective and pleasant way.

A large number of other organizations publishing standards and guidelines exist, but none of them deal explicitly with

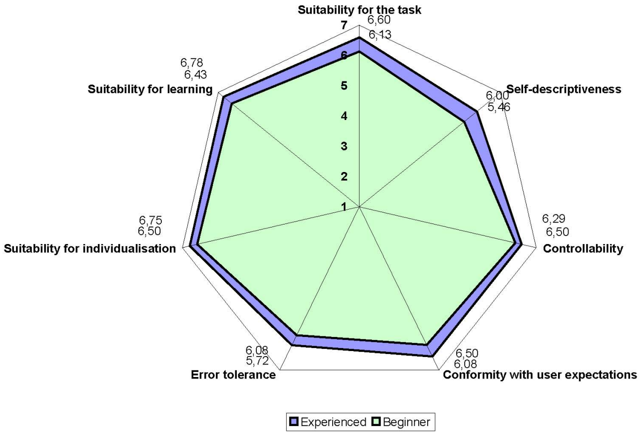

Figure 6. Results of the ISO 9241/10 questionnaire showing the user interface "'quality"' of AMCO. We show the results for two different user groups; a 3D-user interface *beginners* group and an *experienced* 3D-interface users group. All users have already worked before with PDA and touch-screens.

dialog techniques or graphical user interfaces. Moreover, the choice of the ISO-Norm questionnaire allows an efficient time restriction. The ISO-Norm 9241/10 usability questionnaire checks compliance of the AMCO system to ISO Norm 9241/10 and tests the following additional features:

- suitability for the task,
- self-descriptiveness,
- controllability,
- conformity with user expectations,
- error tolerance,
- suitability for individualization
- and learn-ability.

Two questions regarding self-descriptiveness of the application had to be removed since they were related to desktop applications only. The questionnaire is designed for a verbal interview with 30 to 60 minuets per test person. According to the ISO-Norm 9241 part 10, all seven principles of the evaluation are integrated. After an introduction, questionnaires were carefully completed. The test persons experience with PDA and 3D programs was based on a daily routine and at least five hours a week. The first test person required explanation on several points during evaluation which made apparent the need for further question differentiation to eliminate possible ambiguities.

Results and Discussion

The seven principles of the ISO 9241 Part 10 have been basically applied in every UI design and evaluation, although their relevance in different areas of the application has been taken into account. Aspects have been considered are, among others:

- goals of the organization where the user is working,
- needs of the user group,
- different tasks that should be supported by the application.

Hence, it is necessary to consider these aspects before or during the evaluation of AMCO to be able to interpret the acquired data in the correct context.

The evaluation of the usability test results shows that the applied test methodology was well suited for gathering the desired insights on usability and acceptance of the AMCO system. The collected data turned out to be highly informative. They are now serving as a guide for the further perfection of the system. Such informative and conclusive data could not have been obtained by tests in a lab or at simulated environments. One important observation is that the subjects were not only able but also quite happy to fill out the detailed questionnaires after each task. Without such immediate recording of the user experience, the results would not have been as trustworthy and pointed.

Figure 6 depicts the results of the ISO 9241/10 questionnaire showing the user interface "'quality"' of AMCO. The figure shows the results for two different user groups; *beginners* and *experienced* users. All user groups have already worked with PDA and touch screens. The experience of *experienced* users group with PDA and 3D programs was based on a daily routine and at least five hours a week.

Figure 7 summarizes the results of the ISO-Norm usability questionnaire in seven categories; suitability for the task, self-descriptiveness, controllability, conformity with user expectations, error tolerance and suitability for learning.

A closer look at the data reveals that the categories suitability for learning and suitability for task receive a high grading which is very important in this context (cf. fig. 7). The high grade on these categories address the intuitiveness requirement of the AMCO interaction system. Controllability reached a mean value of 6.39 points and suitability for the task, 6.37 points. By comparison, suitability for self-descriptiveness rated worst at 5.73 which is still a high score according to the ISO-Norm scores. In summary, the study achieved a good overall rating of the AMCO software system and its 3D user interface.

To summarize all ratings above 6,00 the majority of users think: AMCO is easy to use, offers all functions to solve tasks efficiently, uses comprehensible metaphors, offers good opportunities to stop the task and continue at the same point later on, allows to change easily between UI parts and menus, can be used in a consistent way, requires little time to learn, encourages to try new functions, does not require the user to remember many details and is designed in a way that things you learned once are memorized well. All of this confirms our main projections for the development of AMCO . The category *suitability for the task* got grade 6.37. It got this grade since some users had problem on some tasks such as shutter movement using the AMCO . For example, users need to navigate the 3D view and make the view bigger in order to perform the shutter movement tasks. The group of users who was beginner to PDA and 3D navigation had usually problem to perform this task. However, this task was easy to do for users who had experience with PDA and 3D programs (see figure 6).

The above-mentioned problem can be divided to *device selection* and *device control* problem. The *device selection* problem of novice users can be improved through the following solutions:

- Scroll bar: by adding a 2D scroll bar on both side of the environment view of the user interface the novice users could easily navigate the view and find their desired device to control.

- ”‘Adaptive Navigation”’: depending on the selected media type, the 3D scene camera moves to a suitable device which supports the rendering of the specific media type. For examples once the user selects a powerpoint slide and holds on it with the stylus then the scene moves to a projector. If the user still presses the stylus on the selected powerpoint slide then the interfaces moves to the next suitable device and so on. It should be also possible to look up devices based on a selected activity (*Preset Actions*) such as ”‘Lighting”’, ”‘HVAC”’, ”‘Printing”’, etc. Preset Actions are listed on the bottom left part of the AMCO user interface (cf. fig. 2)

The *device control* problem of novice users can be improved by applying the following solutions:

- 2D device control interfaces outside the 3D view: through using a two dimensional device control interface like the existing arrows of the presentation control under the 3D environment view of the user interface (cf. fig. 2). When the user clicks on a device, its control interface will be activated.

- Goal-based interaction: by using preset actions the user can just express his goals, e.g. ”‘darken the room”’. The AMCO system decides how to achieve the goal. The required plan/strategy is contained within the preset action. Preset Actions are stored on a room server which exists for each room. For the above example *darken the room* the strategy could be to move down all the shutters in the room, to darken all the dimmers and switch off the lights. A location-aware device discovery is required in order to select the required set of devices and to perform the right actions on them to achieve the requested effect.

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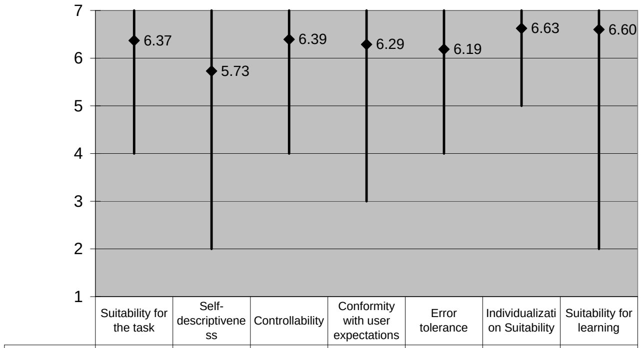

	Suitability for the task	Self-descriptiveness	Controllability	Conformity with user expectations	Error tolerance	Individualization Suitability	Suitability for learning
Lowest Score	4	2	4	3	4	5	2
Highest Score	7	7	7	7	7	7	7
◆ Mean Value	6.37	5.73	6.39	6.29	6.19	6.63	6.60

Figure 7. Mean values, lowest and highest score in seven categories of the ISO-Norm usability evaluation questionnaire for the AMCO interaction system

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