Towards Human Centered Ambient Intelligence

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Abstract. In this paper we present a novel approach to the integration of humans into AmI environments. The key aspect of the concept which we call human centered Ami is a dynamic and active user model which creates a virtual doppelganger of the user on software level. This agent not only complies to the specific characteristics of humans but directly affects and triggers environmental activities. In fact the user's persona and behavior is mapped to system level. Utilizing this doppelganger we introduce the integration of the users' capabilities and skills into the functionality of the environment. Human services enrich intelligent environments and allow to overcome the "all-or-nothing" dilemma which we identified in conventional approaches. The concept of human centered AmI is put into effect within the perception-oriented intelligent environment FINCA. Results of a Wizard-of-Oz experiment with real users show the benefits of the presented approach.

1 Introduction

With the availability of more and more powerful and cheap computing facilities together with their substantially and continuously shrinking size one of the most fascinating visions of computer scientists today appear to be truly realizable: Ubiquitous computing systems integrated into and designed to permanently support the users' everyday life. The principle goal is the "disappearing computer" [1, 2] which silently serves humans whereby they are (most of the time) not even aware of it. Consequently, it is the humans' environment which becomes more "intelligent" – the advent of Ambient Intelligence (AmI).

In the last few years tremendous progress in AmI research allowed for the realization of impressive applications utilizing ubicomp techniques. Prominent examples are so-called Smart Rooms and Smart Houses (cf. e.g. [3, 4]). Here, various sensors and actuators are integrated into the installations of buildings aiming at the support of humans in their private home, or for elderly care, just to mention two examples.

Compared to, e.g., standard desktop applications the key issue in all AmI techniques is the permanent system awareness w.r.t. the global environmental context which is necessary for generating appropriate system reactions. These reactions often depend on hardly predictable actions performed by the very humans to be served. In fact, permanent and reliable context awareness is the main feature of the central AmI paradigm [5–7].

Reconsidering the aforementioned Smart Houses, a principle problem of current AmI applications becomes manifest. For successfully realizing the necessary context awareness at a global scale plus, in this case, the required physical feedback of the system, significant effort for soft- and hardware deployment is mandatory. Numerous sensors (e.g. microphones, cameras, tactile sensors etc.) and, probably more importantly, actuators (automatic door openers, light dimmers, servos for diverse installation equipment like sun-blinds etc.) need to be deployed and in collectivity provide intelligent functionality. If only certain parts of this hardware "zoo" are missing or malfunctioning the overall Ambient Intelligence will fail and the particular Smart House becomes useless. Furthermore and probably more important, a transfer of certain AmI solutions to different but related scenarios requires exactly the same high effort in hard- and software installation. We call this the "all-or-nothing" dilemma which is, in our mind, very obstructive for the generalization of AmI.

In our research we try to overcome the aforementioned "all-or-nothing" dilemma. The motivation for this is the development of AmI techniques which, among others, should easily be transferable between related scenarios putatively exhibiting different hardware settings. More specifically our work is directed to the development of techniques for Smart Houses with special focus on the deployment of perception-oriented approaches analyzing, e.g., visual and acoustic data. Exemplarily integrated into a conference room equipped with, more or less, standard hardware components, thereby explicitly avoiding special solutions like automatic door openers etc., we target our vision of AmI "for the masses".

In contrast to existing approaches for Smart Houses and as the key innovation presented in this paper we propose the explicit integration of human users and their physical abilities into the overall AmI system. Humans are an decisive part of the context and capable of doing numerous things which – for the sake of keeping a system running instead of complete malfunction (see above) – should be used for the design and practical operation of AmI systems. As an example windows or doors can easily be opened or closed by humans if they are – at the right time – asked to do so. The common alternative in standard AmI settings is to integrate some kind of artificial actuator allowing for the automation of the process – the "all-or-nothing" dilemma. Basically, this kind of paradigm shift opens up ways out of the dilemma. Clearly, the user of an AmI system must not be bothered by the system to do anything which would contradict the general vision of AmI. We propose to explicitly integrate humans into the architecture of AmI systems and to make use of their physical capabilities whenever it is appropriate and necessary. Consequently, our approach is directed towards human centered AmI.

The technical realization of Ambient Intelligence environments is in practice based on a Service Oriented Architecture (SOA) [8] which allows for easy modularization and to handle the complexity and dynamics of the system. Related software frameworks like OSGi (cf., e.g., [9]) or Microsoft's .NET currently represent the state-of-the-art and enable transparent communication between certain (software) services dedicated to specific tasks. In this paper we describe a technical realization of the proposed human centered AmI integrated into a Smart House management system which is based on OSGi. As a key contribution for the technical integration of humans into the framework virtual doppelgangers are created, which – at the software level – transparently represent users of an AmI system as any other device. The specific (physical) abilities of humans are modeled by a new class of software services – human services. It is important to mention, that the roles of humans in an AmI scenario might change dynamically. Thus, certain human services principally offered by this person might be disabled (or enabled again). As an example, related to our smart conference room, a person, who is principally able to open the door for a mobile service robot trying to enter the room, should not be asked to do so when he is presenting a talk. Once the person is back in the audience he clearly can be asked to open the door, though. By means of the proposed technique of human services dynamic changes of a person's available capabilities are realized via design patterns allowing for flexible reconfiguration of objects at run time.

In reality the user plays an active, central and determining role in every intelligent environment. However, the analysis of state-of-the-art projects in this field as, e.g., the GatorTech Smart House [10], or the AMIGO platform [11] reveal the fact, that user modeling takes place only within a passive and integral context model. Contrary, in our approach we separate this modeling process and create a user model which adapts to the specific characteristics of humans. In consequence user centered design also at system level is achieved.

In this paper we develop the concept of human services as a tool for the realization of human centered Ambient Intelligence. Human services are designed as a general concept for at least partially overcoming the identified "all-or-nothing" dilemma in AmI scenarios. As a first concrete implementation of human centered AmI we integrated human services in our smart environment – the FINCA which is briefly described in section 2. Following this in section 3 human services are presented in detail. For a qualitative evaluation of the effectiveness of the proposed human services we conducted a practical case-study in the FINCA. Therefore, Wizard-of-Oz experiments with real users of the FINCA's smart conference room were performed and the cognitive load of the users was measured. It is shown, that the application of human services lowers the cognitive load of AmI users which makes the particular systems easier and more intuitive to use (section 4). As a side effect this study shows the acceptance and the intuitive understanding of the concept of human services by the user. The paper concludes with a discussion.

2 A Perception-Oriented Smart Environment: The FINCA

The work described in this paper was conducted within the greater context of a research project aiming at the development of techniques for sophisticated and natural human-computer interaction. Therefore, especially sensor data related to human perception (visual or acoustic signals) are processed using statistical

Fig. 1. Overview of the FINCA (left) and inside view of the smart conference room. Ceiling mounted microphones are marked with red circles whereas the active cameras (also mounted at the ceiling) are marked with blue, dashed circles.

pattern recognition techniques. Serving as an integration scenario for Ambient Intelligence applications a Smart House has been created – the FINCA, a Flexible, Intelligent eNvironment with Computational Augmentation [12].

Basically, the FINCA subsumes two areas under one roof: a smart conference room and, connected to this, an open and flexible lab-space. Within both areas various sensors, namely cameras, microphones, infra-red sensors etc. are integrated. Electro-mechanical sensors (e.g. light switches) and actors (e.g. light or sunblind control units) are integrated and connected via an EIB (European Installation Bus) installation. All sensors and actuators are standard, off-the-shelf components. The reason for this is, that we – for better transferability of developed solutions – explicitly aim to avoid special solutions which are only available for the FINCA. Furthermore, a mobile service robot is integrated into the FINCA. According to its capabilities the robot is used as an "external sensor" and actuator, e.g., for concierge services within the smart environment. For general system integration an OSGi based middleware framework is used.

Ultimately an intelligent, cooperative house environment, which supports human users during various activities (conferences, information retrieval, communication, entertainment etc.) is created. For natural and thus intuitive interaction with the environment special teaching of human users will not be required. Therefore, the FINCA detects, locates and tracks communication partners by analyzing visual and acoustic data. The results are combined allowing for multimodal scene analysis aiming at a successful automatic interpretation of user's intentions.

In figure 1 an overview of the FINCA (left hand side) is given plus an inside view of the smart conference room. The FINCA is integrated into a larger laboratory including numerous machines and working places. Thus, a (realistic) rendering of the actual smart house gives a better overview rather than an actual photo of the Smart House.

3 User Modeling and Human Services

In everyday life humans are confronted with numerous different computer based systems. It is the central aspect of AmI to combine their functions into intelligent environments whose emergent characteristics should generate substantial benefits for the human thereby improving his experience. However, without an integration concept this combination process results in a tangled mass of user interfaces and usage concepts each demanding for specialized knowledge. Eventually, human computer interaction looses all its originally intended intuitiveness and the central concept of assistance is doomed.

In the last few years various approaches addressing this integration challenge have been developed where the focus is, basically, on the creation of context aware AmI environments. The strong dependency on sensors and actuators, however, results in the "all-or-nothing" dilemma as discussed in section 1. The representation of humans at system level, i.e. within the particular middleware frameworks integrating the different software services and hardware control, is realized within in a passive context model. This traditional concept of context awareness, basically, does not cope with the special characteristics of humans.

In this paper we present a new approach aiming at the integration of humans as active components into intelligent environments. The motivation for this is to open up ways out of the "all-or-nothing" dilemma. We target on a user representation within an intelligent environment's middleware framework which explicitly respects the characteristics and specific role of the user in the real world. Thus, it allows for the dynamic integration of human capabilities into the functionality of the environment.

As a concrete technical realization of the proposed concept we create a virtual doppelganger of the user at software level. Separated from the standard passive context model this concept allows for user integration at the service level – human services which represent the key aspect to overcome the "all-or-nothing" dilemma. The functional gap of most intelligent environments substantially depending on the existence of all required hardware devices is closed. The key idea here is to transfer the approach for resolving software dependencies as known from service oriented architectures (SOA) to hardware related dependencies. The central aspect for filling the gap of missing sensors or actuators in an intelligent environment is the dynamic assistance by humans.

In the following the concept of human centered AmI, namely the explicit modeling of users, modeling the users' behavior, and human services are discussed in detail.

3.1 Explicit Modeling of Users

In the research field of ubiquitous computing and AmI the user context model primarily consists of the user's location and his social context. Recent studies, however, argue that modeling only the external context does not comply with the characteristics of humans in reality [13]. Accordingly, an explicit modeling

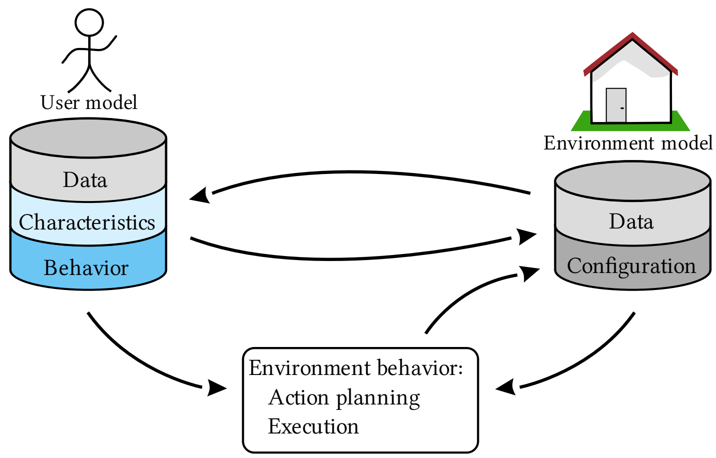

Fig. 2. There is a close relation between user and context model. The state of the environment directly influences the role of the user and vice versa the user implicitly determines the current state of the environment.

of the user separated from a general context model is discussed in the related literature [14, 15].

In fact a close relation between the user model and the environment model exists which constitutes the specific context at system level as illustrated in figure 2. The environmental context (right hand side of the figure) influences the user model (left) and, vice versa, the state of the user model directly affects the general context of the environment. In particular the role of the user within an intelligent environment might change due to changes within the general context model. Therefore, specific user activity is not necessarily to be observed. Similarly, user actions might change the environmental context. In consequence the user model and the context model have to be linked according to interference and integrity rules.

In our approach human users are represented by software objects at system level. This object oriented technique allows for modeling human characteristics and their activities in detail as well as for providing methods for direct communication between the virtual doppelgangers and software modules. Furthermore, intelligent user oriented system behavior becomes possible which accounts for the user's individual characteristics.

3.2 Modeling the User's Behavior

The conceptual goal of virtual doppelgangers is to represent the active and dynamic character of the user within the software framework of an AmI environment. Integral part of this concept is the mapping of user activities to system actions. Consequently, the user model not only consists of passive information about the user and his present state – which corresponds to conventional AmI

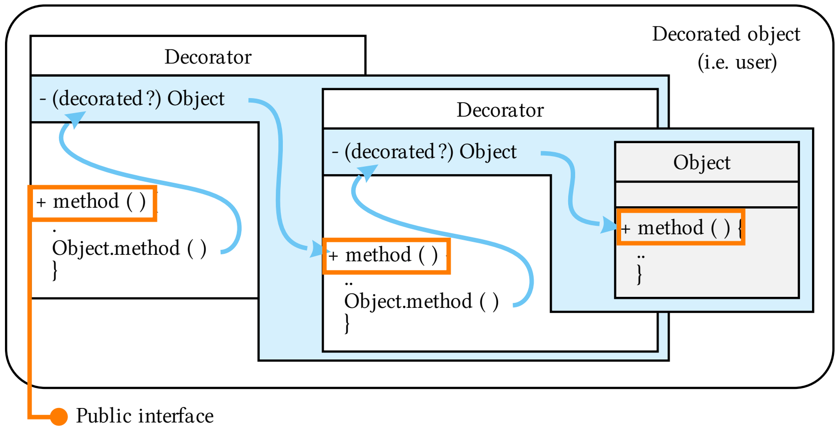

Fig. 3. The decoration of objects, i.e. the representation of the human user, allows for dynamic changes of their methods at runtime. Due to the use of abstract interfaces even multiple decorations and different properties can be combined.

designs – but, instead, is an active part of the system, able to trigger actions. Changes of local user data as well as system activities are controlled by this virtual doppelganger. As an example a single observed user action can lead to a continuous sequence of system actions controlled by the user model. According to its equivalent in the real world the virtual doppelganger becomes a system component which actively and continuously determines the system behavior.

The implementation of the user model at the software level is based on different design patterns [16] to achieve a highly dynamic and flexible virtual doppelganger. The user's attributes and methods can be decorated at runtime allowing to adapt the model constantly (cf. figure 3). Based on abstract interfaces new decorations can be provided by external modules and they can be applied to already existing instances of the user model. By decoration not only static data of the model can be changed but, additionally, the specific implementation of methods. As an example methods which are responsible for the communication between the real human user and his virtual doppelganger can change dynamically allowing to adopt to context information or user characteristics (e.g. to change the modality or language of communication). Consequently, a user centered intelligence emerges.

Utilizing the state pattern the active and continuous role of the user is modeled. Each thread based state is able to use the framework's functionality to control the environmental conditions in accordance to the users activity. For example, the virtual doppelganger could continuously adapt the lighting conditions according to the current activity thus avoiding disturbances of the user.

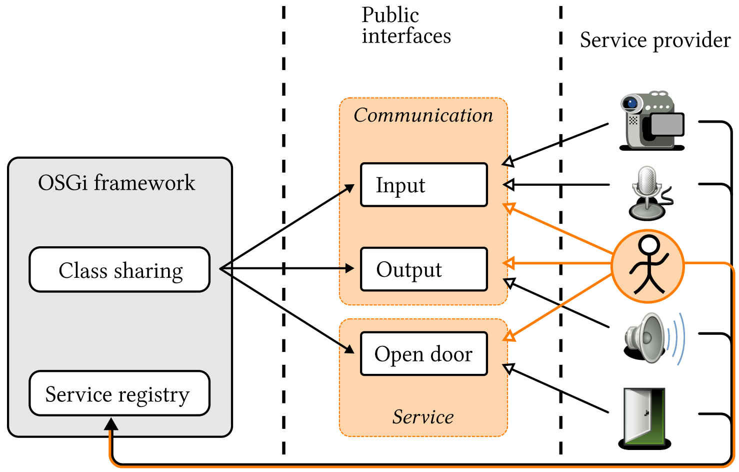

Fig. 4. Abstract service interfaces can be implemented by conventional modules and the user model. The service itself is completely described by the interface and no special knowledge about a (human) service in needed. In consequence human services in usage do not differ from conventional services.

3.3 Human Services

Generally, hardware devices and software modules propagate their functionality as services within the middleware of an intelligent environment. According to this paradigm of service orientation the idea behind the proposed concept of human services is to analogously propagate the capabilities of humans dynamically and dependent on the global context. Consequently, while holding all the user data the user model itself represents the instance to decide which human service to offer or to withdraw. Depending on the information about the human user, the environmental context, and the current activities these decisions about dynamic offering of human services are taken by the user model. In consequence the dynamics of the model affects this process directly and determines the service offering.

The typical SOA of an intelligent environment (as implemented in our own Smart House – the FINCA, see section 2) combined with the explicit user model represent a perfect base for the realization of human services. In our case we use the OSGi framework functions for propagating human services of the user model which, in this case, are implementations of defined abstract Java interfaces. Note that the proposed concept of human centered AmI incl. human services does not rely on utilizing an OSGi framework.

In general those interfaces can be sorted by function in two groups which is illustrated in figure 4. On the one hand there are service interfaces describing skills and capabilities of humans. As an example for the case study presented in this paper (see next section) a service interface describing a door-opening service was defined and implemented. On the other hand there are so called

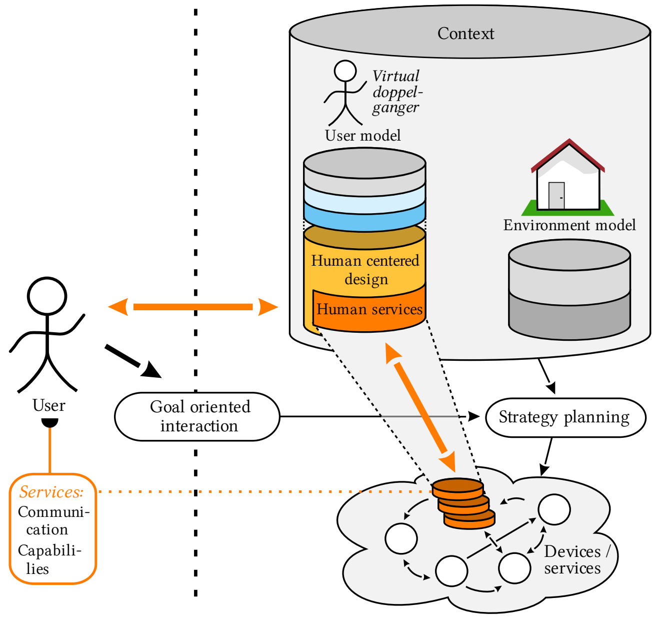

Fig. 5. Human services allow for the integration of the user's capabilities into the action planning of intelligent environments and are the key feature of the approach developed in this paper. On the left hand side the real user is shown, on the right his virtual doppelganger. The integration of the user model into the system is accomplished at service level. The role of the user shifts from being the trigger of system activities to an active component within the overall system. The user model thereby controls the intelligent communication between the user and his virtual doppelganger.

communication interfaces which account for the lack of a direct communication channel between the system and the user. These interfaces provide abstract input and output methods for software modules to contact the user. Dependent on the user's actual state these methods are mapped within the user model to sensor and actuator based environmental functions. Examples of communication services are speech- and handwriting-recognition, visual terminals and speech synthesis. The communication interfaces provide context adaptive communication channels encapsulated by the user model.

Human services extend the role of humans in AmI environments and lead to the proposed user integration at service level which is illustrated in figure 5. In consequence the user is no longer considered to be only the trigger of system activities but, instead, the functionality of the environment is enhanced by the user's skills. Functional dependencies at hardware level as discussed above are dramatically reduced by human services. The intelligence of the environment extends beyond the boundary of physical sensor and actuator installations.

4 Human Services in Action: A Case-Study

Traditionally, AmI systems are evaluated by means of usability studies. Due to the complexity of such systems the evaluation with (naive) users in the loop in practice turns out to be a challenging task with numerous issues to be respected. In particular methods used in HCI studies are not likely to be feasible in situations with disappearing computing. As an example, the communication interfaces are invisible and – at least partially – unknown to the user. Furthermore, often input methods tend to be error prone.

In addition improving the usability in fact corresponds to a multidisciplinary task and, unfortunately, no general solutions exist [17]. The evaluation of a general concept like the one presented in this work raises further questions regarding the methodology of experiments to be conducted. The goal of the evaluation is to measure the overall influence of a system's design on it's usability rather than limiting to some isolated functionality of certain components.

The hypothesis to be verified in the experiments are the following:

1. The concept of human services accompanied by intelligent user interaction lowers the cognitive load of AmI users. In consequence the overall system usability increases and the system becomes easier and more intuitive without the need of precise user instructions.
2. The concept of human services is naturally understood by the untaught user and specific user instructions are superfluous.

4.1 Experiment Design

In these premises we performed a case-study with human services integrated into the FINCA. Therefore, real users were asked to interact with the smart conference room of the FINCA. More specifically they should check and rate environmental functions like speech and gesture recognition, localization and control of lighting conditions. As an example while pointing to a specific light source the user had to give a voice command to turn on the light. A reference sheet explaining the available functionality was given to the subjects before the experiment started. The underlying goal of these experiments was to encourage human users to perform realistic (and unconstrained) interaction with the intelligent environment.

In addition to this rather simple task, in order to evaluate the usability in a cognitively demanding situation, the subjects were given a more complex interaction task. This advanced interaction task is triggered and defined by the following occurrences and accordant solutions. Note that only the goals of this task were pre-defined, the interaction between users and the FINCA remained unconstrained.

- The mobile service robot, which at some point tries to enter the conference room, must be assisted. Therefore, the door needs to be opened by the subject.

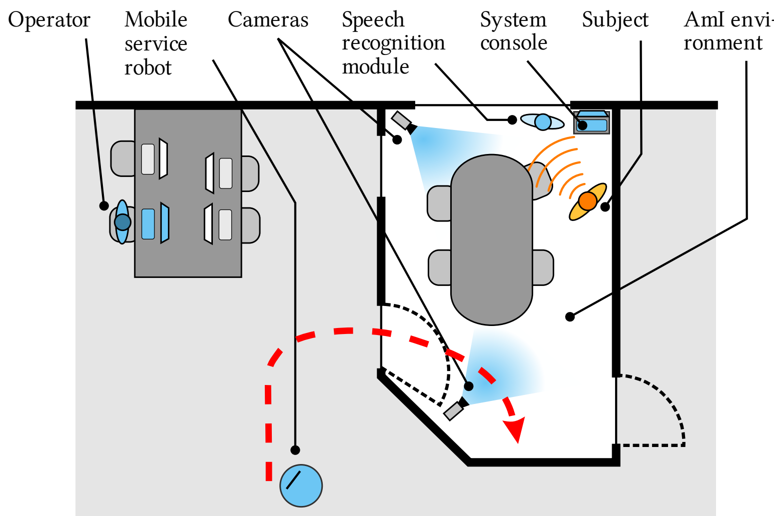

Fig. 6. During the experiment the subject is interacting with the intelligent environment (it's active components are marked blue). Interaction is accomplished via the speech recognition and synthesis module based on an artificial head equipped with stereo microphones and speakers. The operator remains in background out of view of the subject.

– A software module occasionally malfunctioning during the experiment is required to be restarted.

In order to minimize functional influences of (putatively error prone) input methods and to concentrate on the evaluation of the new concept of human services this study was designed as an *Wizard-of-Oz* experiment [18]. Thus, speech and gesture recognition were simulated by an (invisible) operator whereby the particular subject was in belief of using real intelligent functionality of the conference room.

Using installed cameras and microphones the operator monitored the subject and coordinated system activities following a specified and detailed protocol. Speech commands and gestures given by the subject were treated by the operator, outputs to the subject were entered in textform and processed by a speech synthesis module. In order to handle unpredicted incidences the mobile service robot was at some point during the experiment manually navigated into the FINCA. The experimental setup is illustrated in figure 6.

After completion the experiment was evaluated by means of a questionnaire survey. This survey was targeted on the subject's role in the environment, the complexity of the tasks and, finally, examined whether the concept of (offering) human services (e.g. manually opening the door for the robot) were naturally accepted or perceived to be distracting. Answers had to be given based on the 5-point Likert scale [19].

4.2 Dual-task Interference

Although the role of the user in the environment as examined by the questionnaire survey is important concerning the goal of user integration, this survey does not provide a measure of neither the usability of the system nor, in this context, the advantages over conventional AmI concepts. In consequence some additional examination of how the subjects managed to fulfill the advanced interaction task is needed. Unfortunately, standard evaluation methods from HCI applications are often inappropriate (see introduction of section 4).

In order to measure the usability of the smart conference room we additionally performed an evaluation following the dual-task paradigm which evolved from psychological research (cf. e.g. [20]). It addresses the analysis of the cognitive load of humans while fulfilling given tasks. In fact, the cognitive load corresponds to a direct measure of the usability: The lower the cognitive load the more intuitive and, thus, higher is the usability of the smart environment. The basis of this assumption is the fact that people tend to have problems when processing multiple cognitively demanding activities in parallel. The reason for which lies in the limited capacity of certain cognitive resources and the competition of parallel activities for such. This mutual interference of activities is called dual-task interference and is utilized in this study by giving the subjects a second, cognitively demanding and *measurable* task – the control task – in parallel to the advanced interaction task.

The memorization of unassociated information has been proved to be appropriate as control task [21]. In our experiments a multi-digit random number was presented to the subjects and the memorization performance was measured at the end of the experiment. Preliminary tests have identified a nine-digit number, presented in three blocks with 3 digits each, as reasonable. To assure for equal conditions w.r.t. cognitive elaboration the number is not visually presented but read to the subject by the investigator until it was correctly repeated. For quantifying the results the Levenshtein distance [22] is used which conforms to typical errors made in such tasks.

This control task provides a simple yet effective measure for the cognitive load of a subject during the experiment. By design these results correlate with the complexity of the intelligent environment, which is directly connected to the usability.

4.3 Test Procedure

We conducted experiments with 15 different participants (namely undergraduate students), all of them being naive users w.r.t. AmI related research. Three disjoint sub-groups were created by (randomly) splitting the cohort and assigned to one of the following experimental conditions:

1. Subjects contained by the first group are not confronted with extended and cognitively demanding interaction task. The results of the control task are expected to be optimal as no cognitive interference will occur. The results of the memorization task of this control group will serve as reference value.

2. Prior to the experiment the subjects of this group are given detailed instructions on how to solve the advanced interaction task (cf. section 4.1) but at the time of occurrence no interactive help is given. Instead, the subjects must recall the required information. The condition in this group complies with conventional AmI design: The user does not offer a human service which can be dynamically requested by the environment. In order to be able to handle certain situations – i.e. the door needs to be opened, a software module is malfunctioning – the user needs specific and detailed knowledge.
3. The subjects of the last group do not have any detailed pre-instructions on how to handle the advanced interaction task. At the time of occurrence, however, the user is given interactive help by the intelligent conference room. Utilizing human services the environment is able to involve the user's capabilities in action planning, i.e. for opening the door for the robot a service is used which is offered by the user – an instance of a human service. In consequence the handling of the proposed advanced task – a task which exceed the possibilities of conventional AmI – is managed by the environment itself to disburden the user. This is what we call human centered AmI.

As already mentioned, at the beginning of an experiment the subjects received short introductions about the functionality of the smart conference room. Depending on the sub-group the subject belongs to, the particular task description was given to the user. During the experiment the subject was left alone within the FINCA ensuring the completion of the task with as little disturbances as possible. At the end of the experiment the performance in the memorization task was measured and the questionnaire was filled out.

Reconsidering the initial assumptions w.r.t. the practical evaluation the effectiveness of human services can be evaluated. The results of the memorization task measure the cognitive load of the subject during experiment and, in consequence, the complexity of the specific experimental condition. The acceptance of the concept of human services is implicitly examined and further information regarding the perception of the particular subject's role is gathered by questionnaire.

4.4 Results

For the quantitative evaluation of the experimental results we utilized the well-established ANOVA (analysis of variances) method (cf. e.g. [23]), a statistical procedure which evaluates the differences of certain measurements in dependency of the condition of the particular experiment. Basically, different experimental conditions are compared aiming for the analysis of the effectiveness of the proposed human services. By means of the analysis of certain statistical measures differences between the experiments performed by the three sub-groups are investigated. In this case-study the group conditions differ in presence or absence of the proposed human centered AmI (see previous section). Thus, results are analyzed by means of one-factor ANOVA.

In the following the results for the evaluation of both the complexity of the task itself and for the control task results are given.

Task Complexity Although the complexity of both the standard interaction task (see definition of the control group in section 4.3) and the advanced interaction task (second and third sub-group assigned to the actual evaluation of human centered AmI) are comparable, different subjects might differently perceive its complexity. Since it is the general goal to evaluate the memorization results such putative biases need to be eliminated.

In order to measure the complexity of the task to fulfill, a questionnaire – completed by the test persons after conducting the experiment – was evaluated thereby offering standardized numerical answers from the 5-point Likert scale. In table 1 and 2, respectively, the results of this survey are summarized. Table 1 contains the ANOVA measures squared sum S^2, degree of freedom df, mean sum MS, F-test statistics F, and statistical significance p – each w.r.t. the Likert based answers given in the questionnaires. The results of the first row (human centered AmI) are averaged over the three sub-groups with different experimental conditions. According to standard ANOVA presentations and for completeness also figures for random error and total are given. In the second table the descriptive statistics are given separately for the three sub-groups.

Table 1. ANOVA table of general task complexity – no significant changes are caused by the introduction of the proposed human services which allows for direct comparison of the memorization results to those obtained from the control group.

source of variance	S^2	df	MS	F	p
human centered AmI	0.93	2	0.47	0.64	0.5462
random error	8.8	12	0.73		
total	9.73	14	0.7		

Table 2. Descriptive statistics of general task complexity. The results show no significant differences between either groups.

group	N	mean	standard error	standard deviation
1	5	4.6	0.24	0.54
2	5	4.2	0.58	1.3
3	5	4.8	0.2	0.44
total	5	4.53	0.22	0.83

The influence of the experimental condition is given by statistical significance of $p = 0.5462$ which is close to random and the mean differs only marginally.[1]

[1] According to ANOVA the statistics of significance is the probability that the difference in variance between groups is caused by random and not by experimental

It can be seen that the introduction of human services does not change the perceived complexity of the task – which justifies the overall evaluation approach. The results obtained from control group experiments and those obtained when human services are activated are, thus, directly comparable.

Control Task Results In the previous section the general evaluation methodology was justified by verifying the comparability of the general task complexities. Consequently, we can now focus on the main evaluation of the effectiveness of human services. This means the measurement of the cognitive loads of the test persons while conducting the particular experiments either using human services or not. Therefore, the memorization performances of the subjects assigned to the particular sub-groups are compared.

The ANOVA analysis of the mismatches, i.e. the Levenshtein distances between the nine-digit numbers to be memorized and those numbers which actually were reproduced by the subjects, shows a trend towards a significant difference ($p = 0.094$) between the sub-groups of the case-study. In table 3 the particular measures are summarized accordingly. It can be seen that the proposed approach of human centred AmI (group 3) reduces the error rate to a level similar to the control group (group 1) where no cognitive interference was inducted (table 4). Contrary to a conventional AmI system (group 2) the error rate is halved – which gives strong evidence for the effectiveness of human services in related AmI domains.

Table 3. ANOVA table of error rates in control task (memorization of nine-digit numbers during the experiments). The results show a trend towards a significant difference between the particular sub-groups of the case-study which gives evidence for the effectiveness of human services.

source of variance	S^2	*df*	MS	F	p
human centered AmI	22.8	2	11.4	2.9	0.0940
random error	47.2	12	3.93		
total	70	14	5		

4.5 Conclusion

By means of an user-oriented case-study where naive users interacted without constraints in a Wizard-of-Oz setup with an intelligent environment which was designed according to the proposed approach, the effectiveness of human services has been demonstrated. The results of the experimental evaluation show that

conditions. The level of significance is defined as $\alpha = 0.05$ and a difference of significance is given by $p \leq \alpha$. [23]

Table 4. Descriptive statistics of control task results. The results show a substantial improvement in memorization performance by human centered AmI (group 3) compared to conventional AmI conditions (group 2).

group	N	mean	standard error	standard deviation
1	5	1.8	0.66	1.48
2	5	3.6	1.33	2.96
3	5	0.6	0.4	0.89
total	15	2	0.58	2.23

the new concept of human centered AmI not only enriches the environmental functionality as described in section 3. Furthermore, the usability of the intelligent environment has become more intuitive. Evidence for these improvements is given by means of the results of dual-task interference experiments. The quantitative analysis of the memorization performance of test persons interacting with the FINCA shows that their cognitive load is decreased when human services are enabled – the AmI has become easier to use. To summarize, intelligent interaction, user guidance, and the integration of human services in action planning processes allow for intuitive interaction with a complex intelligent environment without the need for detailed pre-instructions.

Furthermore, this case-study shows a natural understanding for the proposed concept by the user. None of the test persons responded irritated when he was asked to help the robot or to restart a software module, i.e. when the subject was asked for a human service. A qualitative analysis of the questionnaire survey unveiled the stronger integration of the user into the environment by the presented approach: The role of the user shifts from a trigger of actions to an integral component of the environment which in fact is the main goal of human centered AmI on system level.

5 Discussion

The key to successful applications within the field of Ambient Intelligence is the permanent system awareness w.r.t. the particular environmental context. In contrast to, e.g., desktop applications, AmI scenarios are based on the integration of various software services running in parallel on different computers.

In this paper we proposed a new concept for direct user integration into Ambient Intelligence environments resulting in human centered AmI. The motivation for this is to overcome the "all-or-nothing" dilemma which we identified for conventional AmI applications: If a certain application relies on specific soft- or hardware services the overall application is hardly transferable to related scenarios where the setup just slightly differs. As an example, AmI solutions developed for Smart Houses substantially depend on the existence of the same hardware "zoo". Otherwise, i.e. if some device is missing or malfunctioning the application will fail completely. We used the example of automatic door-openers allowing a mobile robot to enter a room. If such a device is not available or malfunctioning the robot cannot be used at all and the AmI probably becomes, at least partially, useless.

In order to open up ways out of the "all-or-nothing" dilemma we explicitly integrate human users and their physical abilities into the overall AmI system. Within the software framework of AmI architectures human users are explicitly represented by virtual doppelgangers. These objects are transparently integrated as any other devices (i.e. sensors and actuators) thereby also offering services – human services. Via software patterns dynamic role changes of the human users – depending on their, now explicitly modeled, context and the state of the environment – are realized at runtime. By means of an experimental evaluation within a practical case-study in our own Smart House the effectiveness of the proposed approach has been shown. For a quantitative evaluation we utilized the dual-task interference paradigm. Due to the integration of human services the cognitive load of the users is lowered which indicates a more intuitive usability.

In this paper we presented the general framework for human centered AmI. In order to concentrate on the new concept and to avoid getting stuck in certain practical implementation issues its general effectiveness was evaluated by means of Wizard-of-Oz experiments. Clearly, when entering the real-world such practical details have to be solved. Probably the most important module required is the one which decides whether a human service or some (original) technical service shall be used. In a worst-case scenario the proposed concept would degenerate and human users offering human services are doing all the work – which is far from the original AmI vision. Such decisions, however, can be solved very effectively when integrating global reasoning modules (e.g. based on ontholo- gies). By design such functionalities can easily be integrated into the framework of human centered Ambient Intelligence.

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