Explicit and Implicit Human Computer Interactions in Ambient Intelligence Environments

From Concepts Towards Concrete Implementations in the Active and Assisted Living Field of Practice

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***Abstract*—This work presents the design and development process of Ambient Intelligence Environments from the conception phase, over the implementation phase towards the end user perspective. The focus is on different interaction techniques in Ambient Intelligence Environments and their added value for the end user of such a system.**

Keywords-AmI; explicit HCI; eHCI; implicit HCI; iHCI; architecture; Active and Assisted Living; AAL.

I. Introduction

Ambient Intelligence (AmI) interactions focus on interactions that are supported by, and embedded in, digital equipped environmental settings. As indicated in [1], AmI is a concept that refers to a digital environment that pro-actively, but sensibly, supports people in their daily lives.

In order to reach this goal, it is from utmost importance to consider the contextual information. This is also underlined by Schmidt [2] as follows: "Context and context-awareness are central issues to ambient intelligence. The availability of context and the use of context in interactive applications offer new possibilities to tailor applications and systems on-the-fly to the current situation." The "on-the-fly" adjustment according the current situation is also a central element in adaptive systems [3]. Moreover, AmI systems utilize adaptive systems and the adaptivity factor but with a stronger focus on interactions in digital equipped environmental settings. This, in turn, allows the realization of implicit Human Computer Interactions (iHCI) in ubiquitous and disappearing computing [4]–[6] settings. This is a key element of AmI systems, namely the shift from explicit Human Computer Interaction (eHCI) elements, where users focus on interactions embodied within one single device (e.g., smartphone, tablet device, TV setting, etc.) towards iHCI elements where users can interact with the whole environment. Further on in his work, Schmidt summarizes this juxtaposition of eHCI vs. iHCI as follows:

A. *Explicit Human Computer Interaction (eHCI)*

- The user requests the system to carry out a certain action.
- The action is carried out by the computer, in modern interfaces providing feedback on this process.
- The system responds with an appropriate reply, which in some cases may be empty.

B. *Implict Human Computer Interaction (iHCI)*

- iHCI is the interaction of a human with the environment and with artifacts which is aimed to accomplish a goal. Within this process, the system acquires implicit input from the user and may present implicit output to the user.
- Implicit inputs are actions and behavior of humans, which are done to achieve a goal and are not primarily regarded as interaction with a computer, but captured, recognized and interpret by a computer system as input.
- Implicit output of a computer that is not directly related to an explicit input and which is seamlessly integrated with the environment and the task of the user.

This work focuses on these two interaction types and presents in the first section a literature-based overview about the architectural setting that is needed to realize the eHCI and iHCI approaches within an AmI setting. Section 2 presents a concrete AmI system, which utilizes the mentioned AmI architecture. This development represents the technical point of view regarding AmI systems and the backend, respectively. Section 3 presents two AmI settings from the end user perspective and from the frontend, respectively. This section highlights the eHCI and the iHCI factors where users interact not only with a device but rather with their environment. Section 4 summarizes the work and provides an outlook to future work in this field.

II. Basic AmI Architecture

One remarkable work that summarizes AmI concepts and application was presented by Augusto, et al. [1]. In this work, Augusto presents a general architecture of an AmI system and the corresponding information flow within the system. Figure 1 illustrates components of the general AmI architecture. The top component represents environmental interaction elements. This layer is responsible for the

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mentioned iHCI aspect but at the same time this layer can also provide eHCI artifacts, for instance, as concrete UIs rendered on a smartphone or on a tablet device. The underlying layer is conducted of Sensors and Actuators. These components are responsible for information transfer from the digital world (in terms of bits and bytes) into the physical world (in terms of physical values, e.g., spatiotemporal sensing and smart-home control), and vice-versa. The next component, the middleware layer, is responsible for the aggregation and the harmonization of sensor data and for the delegation of interventions towards different actuators installed in the environmental setting. This is the core component of an AmI system since it orchestrates the whole information flow. The next component represents the reasoner of the AmI system. In this architecture, Augusto refers to Artificial Intelligence reasoning. Negnevitsky highlights the key characteristic of AI in his work "Artificial intelligence: a guide to intelligent systems" with the following statement: "Artificial intelligence is a science that has defined its goal as making machines do things that would require intelligence if done by human" [7]. At this point, it is doubtful if every AmI Setting and thus if a general AmI architecture really requires this high level of reasoning. Nevertheless, despite of the reasoning level, it is understood, that every AmI system requires a reasoner that retrieves the aggregated and harmonized data form the middleware layer and that delegates interventions towards the middleware layer.

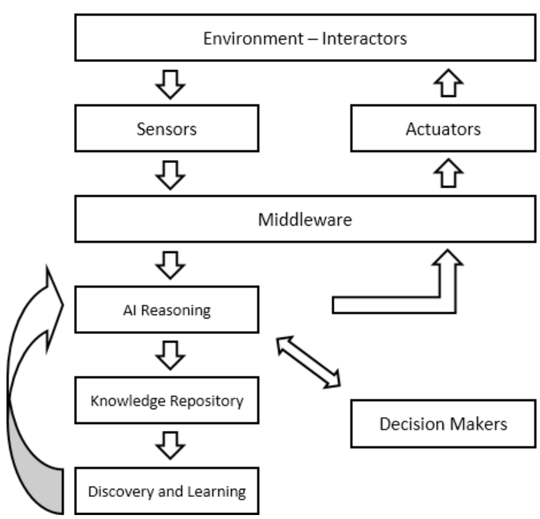

Figure 1. General AmI system architecture and the flow of information [1].

In this work, Augusto uses the phrase "high level decision making process" to explain the remaining components and their interplay. The reasoning is based on the "Decision Makers" component that, for instance, can conclude a set of decision rules, and based on machine learning results produced by the "Discovery and Learning" component. This component requires a "Knowledge Repository" that collects relevant system events and that serves as data provider for the underlying machine learning module.

In the previous section, we have seen that AmI systems relay on physical devices (sensors and actuators) in order to form the Ambient Intelligence environment. Next to the general AmI System architecture, Augusto also presents a generic layout of a Smart Home environment which is equipped with sensors and devices (actuators).

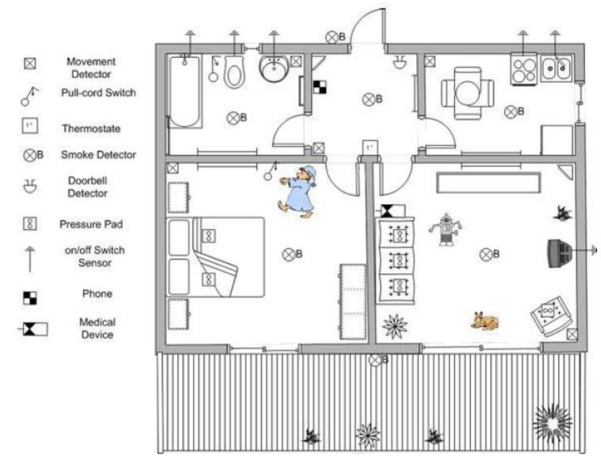

Figure 2. A generic layout of a "Smart Home" enriched with sensors and devices as presented in [1]

Figure 2 illustrates such a Smart Home environment and highlights, that in general, disproportional efforts are needed in order to build an iHCI setting. However, since we are living in a technological driven society it is expected that future technologies and developments will reduce current dominant cost- and complexity factors in building AmI environments. Current products, for instance Apple's HomeKit [8], support this assumption.

III. THE HOMER AMI SYSTEM

Situated in the Active and Assisted Living (AAL) field of practice we have been experiencing the need to build AmI settings in various research projects and developed prototypes [9]–[11]. This resulted in the development of the HOMER [12] AmI system, which can be used across several research projects. The HOMER system utilizes all mentioned components of the general AmI architecture except the AI reasoning on this high sophisticated level. The reasoning in HOMER is bases on a set of finite state machines. Thus, HOMER provides in the first step rule-based reasoning, but it also provides interfaces for external components that build the knowledge repository and the machine learning components. However, Figure 3 illustrates the rule-based reasoning which utilizes finite state machines. States can trigger various interventions and the transitions have a large set of configurable conditions which need to be fulfilled in order to change the system state from one state into another. This example illustrates only one finite state machine within the system. It needs to be mentioned that the HOMER AmI setting supports a large set of finite state machines which are concurrently considered in the decision-making process.

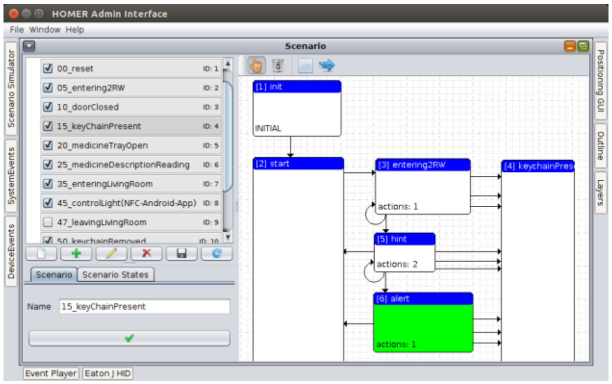

Figure 3. Example of decision making procedure based on finite state machines [12].

Despite the reasoning and the decision-making process, HOMER incorporates various sensors and devices responsible for the communication with the physical environment. Table I illustrates an excerpt of used devices and their purpose within the HOMER AmI environment.

TABLE I. COMMUNICATION WITH PHYSICAL DEVICES IN THE HOMER AMI ENVIRONMENT

Purpose	*Technology/Protocols*
Motion detection	PIR Sensors (KNX, enOcean, Homematic, xComfort)
Indoor localization	RSSI-based localization (iBeacon), PIR based
Smart Home control	Actuators (KNX, enOcean, Homematic, RfxTrx, Tradfri)
Ambient lighting	Smart Lights (Philips Hue, Tradfri)
Energy consumption	Energy consumption sensors (Homematic, xComfort)
Water valve control	Sprinkler actuators (OpenSprinkler)
Environmental Sensing	Air quality, Temperature, Humidity, Barometric, Rain or Wind sensors (RfxTrx, Oregon Scientific)
Activity Sensing	Binary sensors, smart floor, window sensors
Medical Device communication	Weighing scale, blood pressure measurement devices (Near Field Communication - NFC, Bluetooth)
Event tracking	Device usage- based event tracking
Object identification	sensing & control, e.g., door opener, key reminder (NFC)
TV as Interaction device	IR, HDMI-CEC & SmartTV-based

The table is not meant to be holistic, but rather to highlight that the development of AmI environments can be a quite complex procedure. In HOMER, a separate hardware abstraction layer enables the various modules to interact with each other and the rest of the system. HOMER itself utilizes the ISO/IEEE 11073-10471 standard for communication.

IV. THE END USER PERSPECTIVE

Previous sections focused on the AmI concept, AmI architecture and the concrete manifestation based on the presented HOMER AmI system. This section focusses on the end user perspective and highlights eHCI and iHCI aspects within AmI settings.

As already highlighted in the previous section, AmI systems require Smart Home settings. In Figure 2 a generic layout of a "Smart Home" was presented. This illustration is similar to the HOMER setting, since HOMER also supports a representation of the current status within the Smart Home environment. Figure 4 illustrates this representation on a wall-mounted display. The figure highlights the floor plan of a demonstration setting conducted of two living rooms (lower part) and the hall way (upper part). The depicted dots within the floor plan illustrate installed sensors and actuators. Any activity originated form these devices are instantly updated in the GUI. Next to the visual representation, HOMER supports also speech synthesis as an interaction medium in order to inform the user regarding critical situations using the acoustical interaction modality. This is highlighted by the speaker which is located on the top of the wall-mounted display.

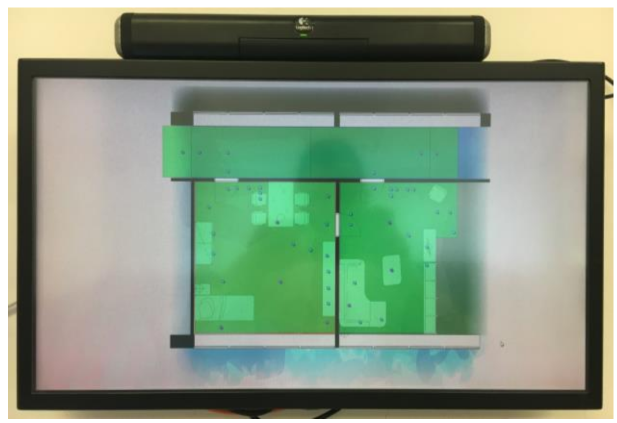
Figure 4. Smart Home status representation on a wall-mounted display including a speaker for the HOMER system speech synthesis.

In addition to the wall-mounted representation, the HOMER GUI can be rendered on any mobile device within this setting but also on TV-devices. This represents the classical eHCI approach where the user requests the system to carry out a certain action and where the system responds with an appropriate reply. As pointed out earlier, AmI environments additionally support the iHCI approach, where users interact with the environment rather than with devices. In the HOMER setting, an iHCI is, for instance, the door or the window opening action. This action is recognized by the system and might cause an intervention by the system if a critical condition is met. Such a critical condition is, for instance, the state where the user has forgotten to close/lock the door after entering the apartment. The system provides in such a case an intervention via the mentioned speech synthesis feature or via a push notification which will be displayed on user's smartphone.

As mentioned before, in our AAL field of practice, we have been utilizing HOMER in various projects and developments. The following example illustrates eHCI and iHCI aspects of AmI environments based on the research project RelaxedCare [9],[13],[14].

The project was performed between May 2013 and April 2016 and was targeting the development of an interactive system for informal caregiver and their assisted persons. The goal of the project was to provide a solution which can reduce the necessity of regularly checking the status of a person in need of care, living at home. Although the project has finished years ago, its concept still represents the state-of-the-art approach regarding AmI, eHCI and iHCI. Figure 5 illustrates the basic idea of the RelaxedCare system. It depicts the AmI setting installed at the assisted person and the communication channels towards the informal caregiver. The overall goal of the project was to provide iHCI artifacts that derive a wellbeing state of the person in need of care. The assisted person primarily interacts with their living environment and less with explicit devices. On the other hand, the informal caregiver utilizes technologies such as the smartphone or an ambient light device to perceive the overall wellbeing state of their assisted person and to start the dialog with the remote person. This setting represents a mixed setting that utilizes eHCI artifacts (smartphone, RelaxedCare cube) and iHCI artifacts (the interactive picture frame, the ambient light device and the RelaxedCare cube).

Figure 5. The RelaxedCare idea depicting the AmI environment in the top half of the image and the communication channels at the bottom half of the image.

This iHCI vs. eHCI juxtaposition becomes even clearer if we take the final prototype into account that is depicted in Figure 6. The figure illustrates the mentioned ambient light device that can be installed on both sides, on the informal caregiver side and on the assisted person's side. The ambient lighting represents the overall wellbeing state of the assisted person. This wellbeing state is derived from activity level, social interaction and daily life routine data, which in turn are provided by the AmI setting.

Figure 6. The RelaxedCare cube prototype that provides the overall wellbeing state of the assisted person via ambient lighting.

Thus, iHCI artifacts are used twofold: (1) to convey the wellbeing information and (2) to collect data for deriving the wellbeing state. Additionally, the solution provides eHCI artifacts by utilizing NFC-based tangible buttons which, when placed on the top of the RelaxedCare cube, cause a concrete communication action towards the remote user or a user-triggered change of the well-being status. Finally, the solution provides several predefined actions such as "please call me", "I feel good/bad" or the emotion in term of "I'm thinking of you". This information is transferred to the remote person to their smartphone and to their ambient lightning device. Here, and once again, the remote user utilizes both iHCI and eHCI factors for the information gathering and for the communication establishment.

V. CONCLUSION AND FURTHER WORK

This work presented the design process from the conceptualization of AmI systems based on a general architecture, over to the manifestation of an AmI system based on the HOMER platform, towards the utilization of an AmI system demonstrated by the RelaxedCare project. Moreover, this work highlighted one of the key aspects of AmI systems, which is, next to the context awareness, also the provision of explicit HCI artifacts and implicit HCI artifacts. In addition to these positive aspects, the work also underlined that the design and the development of AmI systems can be a time-consuming, costly and complex process. Nevertheless, current technological developments, as highlighted earlier in Section 2, indicate that these negative factors can be alleviated in the near feature.

Thus, with respect to future work, our focus will be the incorporation of such off-the-shelf technologies and the stronger focus on the decision-making process including its subparts, namely the enhancement of the knowledge base representation and the enhancement of machine learning algorithms.

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