LsW: Networked Home Automation in Living Environments

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Abstract Due to demographic changes a lot of research in the field of Ambient Assisted Living (AAL) has been done within the last years. Many of the project systems never left the status of a research prototype nor reached real home environments. The "Länger selbstbestimmt Wohnen" (LsW) project is one step beyond the targets of typical research projects and is integrating preexisting (home automation) technologies in home environments to support the elderly residents. Requirements, selection of possible scenarios and evaluation were done in close cooperation with the residents. The integrated AAL system will remain within the flats of the residents beyond the end of the LsW project. Main points of the LsW project were the analysis of current mobile devices like tablets as human machine interfaces for AAL systems, the integration of existing home automation technologies in existing buildings, the connection between the tablet and the home automation components, and the interoperation between several flats.

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1 Motivation for LsW

Due to demographic changes a lot of research in the field of Ambient Assisted Living has been done within the last years. The objective of the "Länger selbstbestimmt Wohnen" (LsW) project is one step beyond the targets of typical research projects. Within this project it is expected that supporting systems will be developed which are integrated into real life environments of elderly people participating in the project and will be left within their flats after the project ends.

This leads to the fact that the project has to develop systems which are closer to real products than to research prototypes and need to be maintainable by external companies after project completion. One of the major key points of this project is not to focus on high-end research prototypes of the next generation, but on the needs of the residents and the support that can be offered by state-of-the-art technologies. Therefore the project tries to combine and extend available market solutions to create new supporting features close to available market products. Next to this these systems will be evaluated to figure out the real benefit of the daily usage. This should help the housing companies to decide on further installations for other apartments not related to a research project. So the motivation of the project is to develop AAL support for elderly, evaluate it and have it directly ready for the market at the end of the project.

2 Principles of AAL Approaches

There are two approaches for AAL technologies which are applied often to AAL projects. One is focusing on home automation with the objective of improving the living situation at home by adapting technical installations for the needs of elderly people. The second one is focusing on the use of mobile IT systems with the objective of offering a kind of assistive companion for the elderly.

2.1 Home Automation Technology

Existing home automation technologies like EIB, LON, FS20, Homematic, Zigbee, and a lot more offer several possibilities to bring extra services or non-invasive health status monitoring possibilities to homes to support elderly people [1]. Others list key points. Challenges of AAL technologies are:

- An extended healthy, active and dignified life for the elderly that is also widely accessible to the low-income strata of society,
- Implementation by using simple low-cost sensor technology, which also makes it affordable to the lower income people,
- Adaptively retrofitting existing home structures with minimal impact, modification and cost,

- The system should be customizable to the individual's needs, as well as to different cultural needs.

Home automation devices are an integral part of AAL technology strategies. To enable AAL research on smart homes, living labs have been established. Those living labs are laboratories that try to emulate real home environments to develop best suited technologies. In Germany, one of the most popular living labs is the Fraunhofer *inHaus* center in Duisburg. Technologies developed here focus on home automation and electronic assistance. The Living lab *ProPotsdam Komfortwohnung* is specialized on comfort, safety and living for elderly. The *DAI Labor* laboratory concentrates on connectivity and networking of home automation to provide access via a home service platform. Also the IDEAAL apartment at OFFIS in Oldenburg is such a living lab concentrating on developing and evaluating different AAL scenarios with real end users [2]. Within the European context, the Philips *HomeLab* in Eindhoven (NL), *LivingTomorrow* in Vilvoorde/Amsterdam (BE/NL), or the Social Informatics Lab—*SILab* in Newcastle (UK) can be mentioned as well. This is far from an exhausting list; websites like www.openlivinglabs.eu or www.aal-deutschland.de list a lot more labs all over Europe and the world. Those living labs provide examples of the use of home automation with slightly different focuses. An international overview of smart home technologies is given in [3] and [4]. Nevertheless, those are laboratories which can only try to imitate the real life homes. However, lots of new challenges arise in reality and therefore real life projects are essential to establish AAL systems well suited to the users.

2.2 Mobile Assistance

Up-to-date IT with small and networked devices increases the users' range of mobility. This includes mobility inside their home environment as well as outdoors. One goal is to monitor the individual status (e.g. medical status) to improve the quality of life and safety. Another important goal is to give the users the possibility to control their environment at any place and any time [5]. While the number of people using mobile devices like smartphones or tablets increases, also the number of APPs grows for controlling e.g. electric devices at home.

By combining strategies of adaption and awareness this kind of technology will eventually become usable as mobile assistants for handicapped users:

- As a passive assistant the system offers information about the devices at home while being away: For example users who have forgotten whether they switched off the oven at home or not are able to check it and control it from anywhere.
- As an active assistant the system can influence its environment and change states: For example the system could switch off the oven by itself if it detects that the user has left the flat.

Mobile assistance means the combination of (small) devices and context-aware applications. In working environments this kind of assistance is developed and used for supporting the worker with information needed in the current situation [6]. The central idea is to carefully select the information for the use in this situation [7].

The approach in AAL is similar: developing an ambient assistive environment based on existing IT-techniques like "Ambient Intelligence" [8] and "Intelligent Objects" [9]. The assistive environment monitors the individual status of the user and the state of the (technical) environment and derives resulting workflows for execution. The system predicts the safety status of the user and it informs him/her with a feedback about possible upcoming hazards, or influences the "environment" to protect the user before any hazardous situation can occur [10].

2.3 Ergonomics and Usability Design

As many technical and especially mobile systems and applications are developed for "younger" users without any handicaps, the design of an appropriate AAL system is still challenging. AAL systems are not simple lifestyle products but have to take into account the usability for handicapped users. Several aspects are essential for a successful development:

- Any device such as a piece of hardware must follow the standard rules of ergonomics.
- Any application or APP as a piece of software must follow the standard rules of software usability.
- Furthermore any application or APP as a piece of software must follow the ideas of accessibility as well as of individual customization.

As the target group for AAL systems consists mostly of elderly and/or handicapped users the approach of a "barrier free" design will be a good starting point for designing those systems. It is not sufficient to use buttons or displays for designing an AAL System. Standards in this field describe the various possible kinds of handicaps [11] and give ideas on how to solve these issues. Nevertheless it is not possible to consider all handicaps as the variety is too broad. The range is from physical handicaps like tremor over cognitive handicaps like blindness up to mental ones like dementia. So a detailed analysis of the target groups is essential.

Beside ergonomics and usability, esthetics are even more important for the acceptance of an AAL product. Especially for AAL systems this means that most users do not like systems which are obviously recognized as being designed for elderly or handicapped users. Examples are smartphones designed for elderly people with big buttons and special colors which usually are not a success in the market place [11].

3 LsW Environment Concept

The project “Länger selbstbestimmt Wohnen” (LsW) goes beyond a typical research project. Beside its short duration and its small budget some more aspects make the project special.

The origin of the project is not just technically driven but inspired by the residential market. A main partner of the project is a housing company (HC) which is aware of the demographic changes and the resulting needs of the residents. Therefore they plan to offer adapted flats to the elderly as a new target group. To acquire more knowledge about the special needs of this target group the potential users were involved into the development of this project. This was done by performing workshops during the project where the project partners and the prospective users collaborated to develop system requirements. Within a first workshop the users were asked to collect daily problems without discussing any possible solutions for that. Afterwards the research groups tried to identify technical solutions for some of these daily problems and presented these results in a second workshop to the prospective users. At the end there was a list of features which afterwards were implemented and integrated in the flats of the residents.

It is special to the project that its outcome is not a simple prototype or demonstrator but a real product which remains in the flat and stays with the users after the end of the project. That leads to the fact that the system must work stable for a long time. Furthermore it must be easily maintainable which means that the software has to be adaptable as well as the hardware components have to be replaceable by a technical service team and not only by the involved researchers.

3.1 The Living Situation

One more aspect makes the LsW project even more special. This is the living situation within the building LsW is integrated into. It is a house of 10 parties with an unusual high grade of social networking between these parties.

Social networking in this context means the real world interaction between the people living there. Everyone knows and helps each other if necessary. They have a shared flat for meetings and also guests. New residents are not selected by the HC but by the current residents to support this social spirit. This is quite interesting as the average age of the residents is higher than in other living environments. Most of them are already retired. This means special needs and therefore special scenarios to be developed in the LsW project, but also very specific opportunities for designing AAL services like in-house alarm systems to inform the neighbor in the case of emergencies or forgotten household devices left switched on.

3.2 Home Automation Concept

Originating from the workshop results several scenarios were extracted and decided to be realizable within the project. Most of the scenarios are based on home automation technologies which allow for the integration of multiple features with one set of home automation actors and sensors. As a result of the workshops the following scenarios were developed within the scope of home automation technologies.

3.2.1 Scenario: Everything Switched Off

The first scenario is called "Everything Switched Off". This means for the resident of the apartment just a new light switch next to the entrance turning off all lights, power outlets as well as the cooker. From the conceptual point of view this is more difficult. It has to be decided how to switch on the power outlets on arrival as well as to decide which devices should be switched off/on automatically and which devices need to be handled semi-automatically, as for example an electric iron. This device should be switched off on leaving the flat, but not switched on automatically when returning. Therefore a simple traffic light metaphor was created. All power outlets marked by a green spot are declared to be no safety issue. Therefore only devices like TVs or lights should be plugged in there. Power outlets without any mark are conventional and will be therefore not affected by the "Everything Switched Off" scenario. These power outlets may be used, e.g., for devices like a fridge, alarm clocks or phones. The last category of devices is connected to power outlets marked red. To this category belong all devices which must be switched off when leaving the apartment, but must not be switched on again automatically on arrival. The most important devices are the electric iron and the cooker. For example, if an electric iron was already forgotten on leaving the apartment it will stay most likely forgotten on arrival back in the apartment. This could lead to an fire in the apartment on arrival of the resident which would be as undesirable as a fire during the absence.

The electric iron will be often plugged into different power outlets and therefore it was decided to use a mobile adapter instead of the power outlet adapter which is permanently attached to the device and not to the power outlet in the wall. It also has a Switch-On-Button and therefore allows for switching it on again manually, even if the power was switched off automatically by the home automation system.

The cooker received its own Power-On-Button. This push button has two selectable push states. The first and probably normal state is "Switch on the cooker for 30 min". This will activate the power line of the cooker for 30 min and switches it off afterwards as normal cooking ends mostly before that timeout. If the cooker was switched off manually before, it will not be noticed by the resident at all. The second option for the push button is the "Permanently On"-option. This may be used for more complex meals which take more than 30 min. The Global-Switch-Off-Button next to the entrance will power off the cooker in both cases.

3.2.2 Scenario: Everything is Closed

Next to this Global-Switch-Off it was stated by the users that they often come back to their flats because of checking the windows once again. The first idea to address this issue was to close the windows automatically, but as a result of the workshop the residents wanted to do that on their own. This leads to the “Everything Is Closed”-scenario. If someone leaves the flat and presses the Global-Switch-Off-Button used for the “Everything Switched Off” scenario the “Everything Is Closed” scenario is started. It checks all the windows and presents a phrase in native language to the user stating in which rooms windows are left open. The sentence will be presented through a tablet mounted next to the entrance. Speech synthesis algorithms generate the spoken text.

3.2.3 Scenario: Everything is Save

The third scenario is called “Everything Is Save”. It focuses on the handling of fire alerts which seem to occur pretty often because of forgotten cooking activities. Therefore fire alerts detected by smoke detectors are not only presented in the apartments of their occurrence, but are also forwarded to the other apartments. In these apartments the speech synthesis is used again. It gives repeating information about the location where the fire was detected until the user confirms the fire alert by pressing the Global-Switch-Off-Button in his/her apartment. Next to the audio notification within all apartments also all lights will be switched on to improve orientation on the way to the exit. This scenario is a good example of the benefit of the existing living situation in the house where everybody knows and trusts in each other.

Next to the features to be implemented for the elderly some simple features for maintenance have also taken into account. As all the home automation devices should be integrated in already existing living environments it is most likely that a least some of the devices will be powered by a battery. Therefore the maintenance crew needs to know about empty or damaged devices. Should one of the devices send a low battery state, it will cause an automatically generated mail which is sent to the maintenance center. This will make handling of the home automation much easier for the elderly and also for the housing company.

3.3 Mobile Assistance Concept

Beside the home automation support a mobile assistance system for the residents was also developed, i.e., a passive assistance inside their flats. As a central device a tablet was selected with an APP which gives the residents the control of the home automation as well as support on communication. The tablet was chosen as it can be carried around easily within the flat. Furthermore the touch interface of these devices appeared to be highly intuitive and understandable for the users.

The first scenario of mobile assistance to be considered for the concept was to inform about the state of the home automation: The resident is empowered to gather the information if a device in another room is switched on or off and to control it from anywhere. So he/she can avoid unnecessary movements. Mobility in this context means that the resident has the opportunity to control his/her environment from anywhere in the flat using the tablet and not being forced to go to a special place to do so.

In the workshops it was explained to be important that any control action has to be activated by the resident him/herself. The idea of letting “the system” control devices (e.g. lights, ovens) by itself was not appreciated by the users. It was not so much the fear of being patronized but the fear of getting more and more inactive and not longer self-activated. The residents know about the importance of self-activation for staying independent and wanted to have that included in the design of the system.

A second aspect that was seen as helpful for the residents inside their own flat is the support by mobile communication. This was achieved by two special sub-scenarios:

- The mobile assistant is connected to the “Everything is Save” scenario. Speech synthesis on this tablet is used to inform the resident if a fire alert occurs in one of the neighbors’ flats. The goal was to give the resident a more secure feeling in the way that he/she can rescue themselves or prevent neighbors from being hurt and help them in any possible way.
- The mobile assistant supports the communication to the outside of the flat. On the workshops it was reported that it often takes a long time for the resident to react if a visitor rings the door bell. Due to physical handicaps some residents are slow in reaching the door and opening it. So visitors may leave thinking that no one is at home, while the resident is still on the way to the door. The idea to improve that situation was to connect the tablet to the door bell system including its video, voice and control subsystems: a camera at the front door transmits an image stream of the entrance to the tablet. So the resident sees the video of the visitor and can use the tablet to talk to him/her and to open the door if necessary. Again this is possible from any place inside the flat avoiding unnecessary walks for the resident.

A side effect in terms of communication is given from the basic functionality of tablets connected to the internet. It is the possibility to use standard tools like internet browsers or even Skype.

While the assistive functionality with its “logic” should stay in the background of the (software) system to not to irritate the user, the design of the user interface is an essential point in the project.

The first design was influenced by typical interaction design paradigms for tablets. A graphical user interface with elements to be activated by touch interaction was prototypically implemented. To control the flat the user first had to choose the room and in a second step to choose the switch or socket he/she liked to

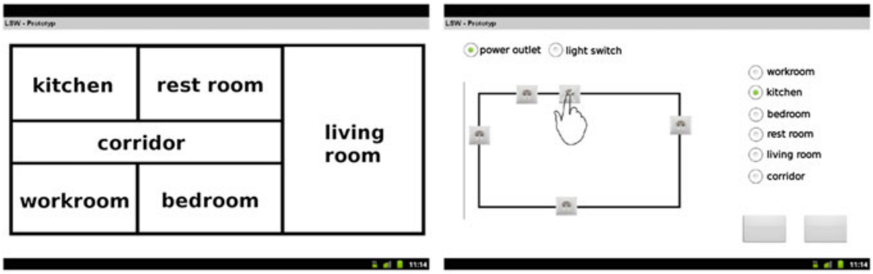

Fig. 1 Graphical concept of the user interface for the home automation subystem of the LsW application

control (see Fig. 1). The idea was to give the user the total control on any single switch and socket in any single room. During the workshops it was figured out that this interface was much too complex for the residents. So it was replaced by a simpler and more textual design (see Fig. 2). Even if this leads to more text to read for the users, it made them feel more comfortable with the system.

One more challenge for the user interface of the LsW application was the complexity of the whole system. Not only the home automation but also communication in terms of the "Everything is Safe" scenario, the door bell and internet as an extra option had to be considered in the design. This lead to the idea of a central application which starts and shows those sub-applications which are currently used and hides all others (see Fig. 3).

Fig. 2 Home-24 App for tablet PCs [12]

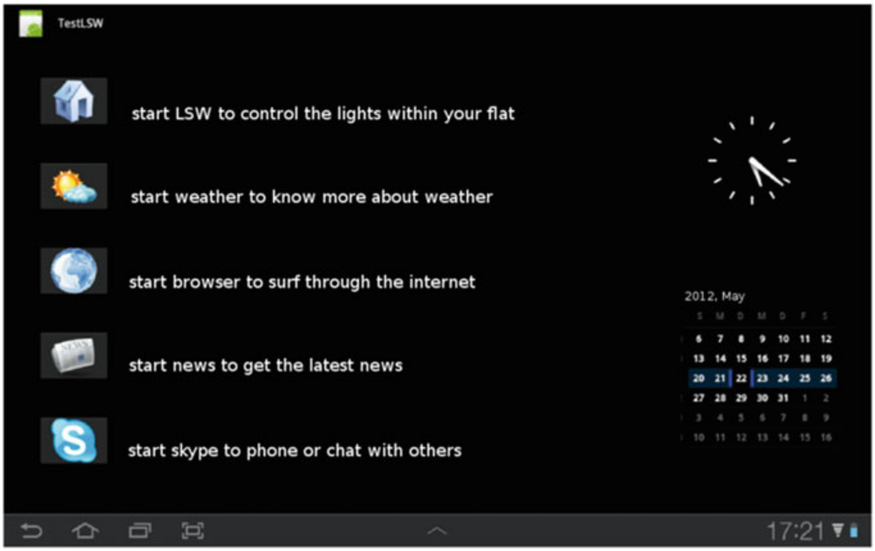

Fig. 3 Concept for the LsW main application

4 Realization of LsW

Due to the fact that the system has to be more stable than a prototype at the end of the project, it was decided to use mostly off-the-shelf technology already available in the market and extend it by the features needed in addition. Because the apartments are already existing and people are living there, radio based home automation devices were chosen. This makes the necessary modification of the apartments quicker and easier.

Figure 4 gives an overview of the overall architecture developed for the LsW scenario. The boxes marked as apartment A, B and C represent the three apartments to be used within LsW scenarios. Apartment A is shown in the figure in more detail than the other apartments whereas the functionality added is the same for all apartments. Due to safety and security reasons it was decided to use as much of the already available cable-dependent infrastructure as possible. All lines marked as wired (phone line and wired Ethernet) belong to the infrastructure which was available within the building before project start. Every apartment has its own phone line whereas the internet connection is shared between all parties of the building. This is in fact an untypical configuration for German buildings, but still a good base for the LsW scenarios. Every apartment got a wireless access point for distributing wireless LAN within a single apartment. This access point also distributes phone calls by using the SIP [13] standard or ordinary phone connectors. By setting up an AVM FritzBox 7390 [14] it is now possible to have an audio/visual connection from the door bell (lower middle) through the central router (center) to each wireless access point of each apartment finally ending at a

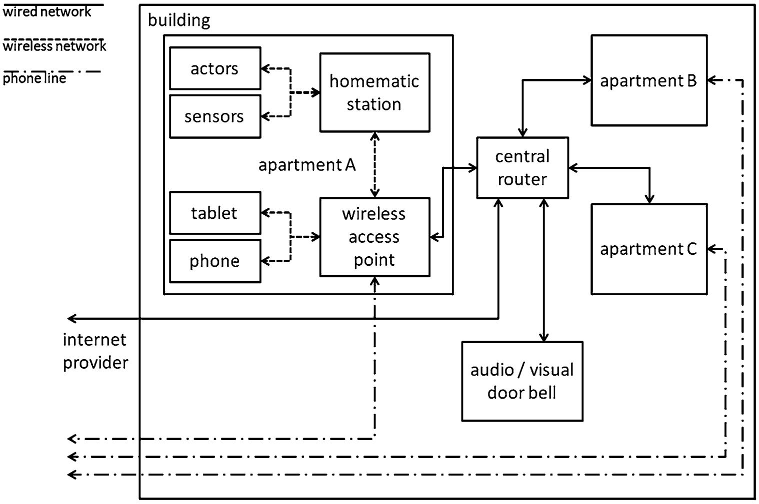

Fig. 4 Basic structure of components within the LsW scenarios

SIP-softphone installed on an Android tablet (e.g. in apartment A, upper left). Next to this the same software on the tablet can also be used to perform an ordinary phone call on the phone line. Crossing the wireless access point and the central router it is also possible to exchange messages between each Homematic [15] station placed within the building. Therefore, e.g., smoke detected by one of the smoke detectors placed in apartment A can notify a user in apartment B by switching the light on and playing spoken texts and alarming sounds within this apartment.

The following section describes the development of the scenarios in more detail.

4.1 Home Automation Realization

All home automation actors and sensors placed within the apartments are based on the Homematic system already introduced within the home automation technology section. Next to this an AVM FritzBox 7390 was used as wireless access point as this device supports also SIP phoning which is important for the communication scenario. As an Android tablet the Samsung Galaxy Tab 10.1 [16] was added to the scenario for speech synthesis and visual notifications within all home automation scenarios.

As already described power outlets to be switched off when leaving the apartment are marked green or red. By checking the devices within the flats it was noticed that all devices to be marked safety critical and therefore labeled red are

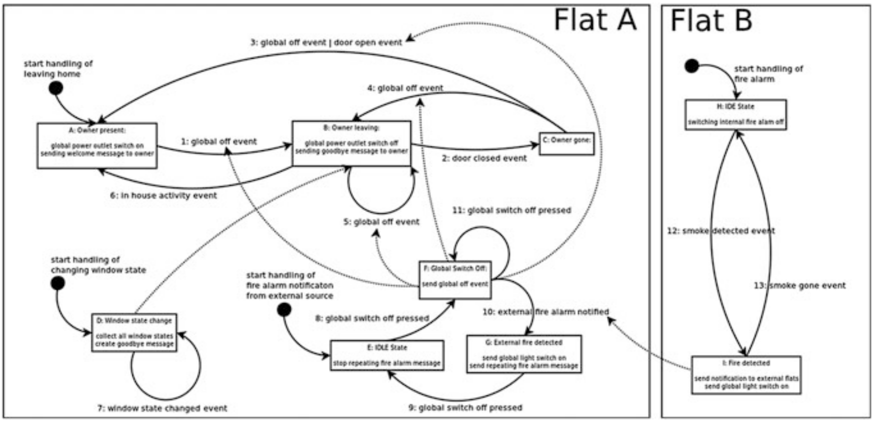

Fig. 5 Final state machine to describe the home automation scenarios developed in the LsW project

not fixed to a specific power outlet and as a result all critical devices got their own power adapter including a switch to reactivate the device after switching it off globally.

Figure 5 gives a brief overview of the final state machines which were implemented during the project. It consists of four different state machines for switching the light off, handling fire alerts in the users' flat and also in remote flats, and also handling window state changes. All these scenarios interact with the single Global-Switch-Off button at the entrance door. This will be described more in detail in the following section.

In the upper left corner the main state machine for controlling lights and power outlets is placed. It consists of three states: Owner-Present, Owner-Leaving, or Owner-Gone. In the state Owner-Present the power outlets are switched on and the lights are controllable. Once a Global-Off-Event was received the Owner-Leaving state is reached. This can only be the case if the Global-Switch-Off-Button was pressed and currently no alarm in the owners' or a remote flat is noticed by the system. Should the owner right after pressing the Switch-Off-Button close the entrance door it is expected that the resident left the apartment. Should this not be the case, because someone closes the door but continues to stay in the flat, every action within the flat noticed will bring the state machine back to the Owner-Present state and switch on the green power outlets. This could be switching on a light, opening a window or switching on the cooker. The only exception is another Global-Off-Event. This will bring the automaton back to Owner-Leaving state.

If a Global-Switch-Off-Event was recognized by the system not only the devices will be switched off, but also a text will be spoken informing about the window states within the whole apartment so to not forget any windows left open. For performance issues of the Homematic control center this sentence is prepared in advanced every time the state of a window changes. This allows for reducing time gaps between pressing the Global-Switch-Off-Button and the spoken reaction by the system. As this was a problem during the first development in the project the automaton in the lower left corner was introduced to the system.

As already described above, the Global-Switch-Off-Button is designed to be used for several scenarios. In the case of a remotely detected fire (in the figure caused in flat A by flat B) the automaton in the lower middle is triggered. This state machine will deactivate the Global-Switch-Off-Event first and replace it by the Remote-Fire-Alert-Noticed-Event and therefore will not automatically switch off the lights anymore on pressing during fire alert. Next to this all lights in the flat will be switched on by the event and an alarm will be presented generated by the tablet. This alarm is also spoken text next to an alarm signal which will be presented in loops until the Global-Switch-Off-Button is pressed. The spoken message informs the residents about the fire alert, especially about the location of the fire. This will allow for offering help and makes emergency calls even quicker. The communication between the different apartments is done via LAN. As all apartments use the same internet connection the data can be routed in between the building using the LAN. This is safer regarding the connection origination than Wireless LAN which would have been also a possible solution.

4.2 Mobile Assistance Realization

For the implementation of the mobile assistance a Samsung Galaxy Tab 10.1 was chosen as the hardware platform. One main reason was that the Android Operating System used on these tablets offers easy solutions for the implementation of mobile assistance due to well documented APIs and a complete set of sensor infrastructure.

Due to the chosen operating system the LsW "application" was implemented as a set of Android "APPs". As introduced in the concept this set has a central APP as its backbone which organizes the specialized APPs for home automation and communication. These "sub-APPs" are running all time in the background. If activated by the user the central APP gives the focus of the user interface to the activated APP. This allows for running all intended functionalities in parallel. An example should clarify the idea: The resident has his/her tablet with him in the living room. The LsW APP is running on it. A visitor rings the door bell and the LsW APP gives the focus to the APP for the door bell control. The resident can now see who wishes to visit him and may open the door using this APP. To make it easier for the visitor to find the way to the living room, the resident changes the focus to the home automation APP and switches the lights in the corridor on. He/she can do all that while sitting in the living room.

An advantage of this modular concept for the LsW system is that changes in functionalities can be implemented easily without influencing the other parts of the system. This advantage was used in the very first steps of implementation. APPs developed from third parties like the Home24 APP for controlling the home automation could be integrated and tested while other APPs were still in the design phase.

5 User Acceptance

The implementation of the project was done stepwise. While the concept of the home automation and the implementation of the mobile assistance could be done in parallel, the installation in the real environment in the flats of the involved residents was done in separate steps.

The experiences of the installation in the first flat including the first user (residents) experiences could be used to improve the installation in the second flat and after that in the third flat. This process improved the installation in terms of getting better and shorter by every flat. Unfortunately it had the disadvantage that the final user studies could start rather late in the project.

At the moment while this paper is written, the user study with the targeted number of residents was just started. So no report on the user acceptance can be given here and now, but will be presented in the talk at the AAL-Conference in January 2013.

6 Gained Experiences So Far

Even though the user studies are ongoing some experiences could already be gained. These can be divided into three aspects:

- Common individual user experiences,
- Technical experiences, and
- Design experiences.

Common individual user experiences

In general the first user experiences can mostly be seen as fighting some psychological fears. This was shown by the results of the first workshop where the idea and some technical demonstrations were presented to the residents. As many components have to be connected wirelessly one main fear was the effects of the so called electrosmog on the residents. There were also some other reported fears the technical system could somehow not work properly. This fear appeared to originate from bad experiences with other technical systems. Those common fears were accompanied by fears stemming from individual experiences having mostly their origin in the knowledge of their own age-dependant handicaps. So some residents felt threatened by the technique itself: they feared to be overburdened by it. Furthermore there was the fear of confusion by switches having different functionalities like a usual light switch, the "Everything OFF" switch and the timed switch for the oven.

Most of those fears could be dealt with or at least be reduced by intense follow-up workshops. But for future projects it is important to consider those and similar psychological aspects as early as possible in the projects.

Technical experiences

Two main points have to be reported so far. The first one is that existing and available components are sometimes quite too focused on some special situations and scenarios. This leads to problems that may occur when using those components in combination with other IT systems, which is one of the tasks to be performed to fulfill the objectives of the project. These issues might be solved in future when more systems are available in the marketplace and the needs for interoperability of those systems are getting stronger.

The second issue figured out so far is that all these home automation installations must be strongly individualized for every apartment and its residents. This might lead to the point that only a specialized company or in the first step a specialized employee will be able to install and maintain those systems such as an AAL integrator.

Design experiences

Closely related to the psychological experiences are the experiences in terms of design. This does not only mean the design of the system and its user interface but also the design (and the concept) of how to train the users on the system:

- Signs/Icons and/or texts of newly installed components must be easily understandable for the users. To design a system according to this requirement it must be taken into account that the targeted user group is elderly and maybe handicapped people.
- The design of the user interface must also respect that the target group might not really be used to devices of the newest technical generation. So the usage, e.g., of a tablet needs to be discussed before integrating it in similar projects.
- A challenge of the design in LsW was the synchronised combination of analogue and digital user interfaces. This was seen especially in the kitchen. The installed ovens often have analogue, mechanical butons to control the temperature of the oven. If an APP (from some mobile device) influences the oven, e.g., changes the temperature it is essential that not only the digital user interface (the APP) changes but also the analogue one. Both interfaces must be absolutely sychronised.
- A good introduction of the system in terms of an intensive training of the prospective users is also essential. This helps to make the user/resident accept the system.

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