Potential and Requirements of IT for Ambient Assisted Living Technologies*

Results of a Delphi Study

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Keywords

Health information technologies, Delphi study, health services for elderly, medical informatics, ambient assisted living

Summary

Objectives: Ambient Assisted Living (AAL) technologies are developed to enable elderly to live independently and safely. Innovative information technology (IT) can interconnect personal devices and offer suitable user interfaces. Often dedicated solutions are developed for particular projects. The aim of our research was to identify major IT challenges for AAL to enable generic and sustainable solutions.

Methods: Delphi Survey. An online questionnaire was sent to 1800 members of the German Innovation Partnership AAL. The first round was qualitative to collect statements. Statements were reduced to items by qualitative content analysis. Items were assessed in the following two rounds by a 5-point Likert-scale. Quantitative analyses for second and third round: descriptive statistics, factor analysis and ANOVA.

Results: Respondents: 81 in first, 173 in second and 70 in third round. All items got a rather high assessment. Medical issues were rated as having a very high potential. Items related to user-friendliness were regarded as most important requirements. Common requirements to all AAL-solutions are reliability, robustness, availability, data security, data privacy, legal issues, ethical requirements, easy configuration. The complete list of requirements can be used as framework for customizing future AAL projects.

Conclusions: A wide variety of IT issues have been assessed important for AAL. The extensive list of requirements makes obvious that it is not efficient to develop dedicated solutions for individual projects but to provide generic methods and reusable components. Experiences and results from medical informatics research can be used to advance AAL solutions (e.g. eHealth and knowledge-based approaches).

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1. Introduction

The demographic change in industrialized nations leads to challenges for welfare structures, in particular for health care systems. Reasons for this change are the increase of life expectancy and declining birth rates. Therefore, projects have been started in Europe to develop research strategies to cope with these challenges. FUTURAGE [1], for example, was funded by the European Commission with the aim of creating a road map for ageing research covering the areas of biogerontology, social and economic resources, environments of ageing, healthy ageing, and user involvement. The road map recommends investigation of ageing research infrastructure and additional capacity building at different levels. According to [2] processes and structures in health care systems of developed countries have to be restructured to lower costs and to ensure high quality care for all patients in the future.

Ambient Assisted Living (AAL) is an umbrella concept for a multitude of devices, services and information and communication technology (ICT) assisting citizens in their own homes and supporting their mobility by means of innovative technologies [3]. For optimal assistance the components used by an assisted person are linked and their entirety builds the individuals' AAL system. An aim of AAL-technology is for example to support citizens in the activities of daily living (ADL) by using sensors, which can automatically detect the user's needs and status. Early detection of diseases and therefore more effective treatment seem to be possible, e.g. by continuous surveillance of vital signs. AAL projects are interdisciplinary: they often provide health care solutions, but they also involve home security, housekeeping, social environment, or mobility [4–7]. The European Innovation Partnership on Active and Healthy Ageing [8] emphasizes the importance of medical aspects and develops a strategic implementation plan with recommendations and future action in the fields 'Prevention, screening and early diagnosis', 'Care and Cure', and 'Active ageing and independent living'. The 'Whole System

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Demonstrator Program' [9] has investigated the efficacy of telecare and telehealth. About 2600 people with social care needs in the UK were included in a multisite, cluster randomized controlled trial as potential long-term users of telecare and telehealth equipment [10]. Results have shown, that telehealth is associated with lower mortality and lower emergency admission rates [11].

Since confidential medical data are processed by AAL-solutions, it is especially important to treat these data in a safe manner. According to [12] more than half of the AAL projects in the EU are focusing on health and home care.

This shows that there are several research challenges for medical informatics in this area, for example behavioral and movement profiles have to be generated, analyzed and automatically interpreted. This can be used for assisting treatments by individualization and adaptation to patients' preferences to decrease duration or severity of diseases [7]. In future, it might be possible to detect age-related diseases, such as dementia [13, 14] at an early stage.

A lot of promising AAL-technology has already been developed [15–17]. A wide variety of projects are testing different approaches and technologies [18]. Success and sustainability of AAL solutions will not only depend on high quality of technology but also on excellent information management and ICT. In contrast to FUTURAGE, the EU research project 'Bridging Research in Aging and ICT Development' (BRAID) [19] focused on information and communication technology (ICT). BRAID developed a vision-driven research agenda and an implementation strategy for their key aspects 'Independent Living', 'Health and Care in Life', 'Occupation in Life', and 'Recreation in Life' by consolidating existing roadmaps and by describing and launching a stakeholder coordination and consultation mechanism [20].

Independent of a particular vision and particular application areas, tasks of information management for AAL reach from analysis of personal profiles over personal treatment reminders to the integration of AAL data into electronic health records, interaction of AAL components and integration of new components at a person's home. If applied appropriately IT can ensure secure and comfortable access to data and applications within a personal AAL system. The challenge will be not to overwhelm elderly with technology, because they are currently regarded as less computer or technology literate [21, 22] and less likely to accept technological advances [23].

Interoperability, appropriate and secure user interfaces, storage, reporting of data and interoperability [24, 25] have to be addressed as major IT challenges. A German working group on AAL and interoperability performed a comprehensive analysis of existing standards and norms for interoperability of devices and sensors, networks and bus systems, data formats, and software platforms, which shows the enormous heterogeneity and complexity of the field [26].

Additionally, ethical (e.g. data handling), social (e.g. user acceptance, public relations), economic (finance), and legal challenges and conditions like the Medical Devices Act [27] and data privacy [28] have to be considered to provide sustainable and well accepted solutions. The European Commission is striving for a comprehensive reform of the European data protection rules from 1995 to strengthen online privacy rights and provide a uniform law for all EU member states.

The topics mentioned above are relevant in a great variety of AAL projects and suggested research activities. Currently most of these projects try to find dedicated solutions to these questions. Unfortunately, hardly any general IT solutions and information management methods are available that can be applied to AAL projects.

Projects like FUTURAGE and BRAID have shown the variety, complexity and scope of research tasks which are necessary for health aging in the future.

This variety of challenges cannot be solved immediately and a prioritization of topics that have to be dealt with is not yet available. Therefore, our research question is, which are the most relevant IT challenges in the AAL context. In Germany we are faced with a variety of available technology and technology that is being developed. Therefore, we are collecting experiences from AAL-projects, reflecting major IT challenges these projects have already identified.

2. Methods

We conducted a Delphi survey, which is a well acknowledged method for identifying prospective developments and trends. A Delphi study is a multi-stage process that relies on an expert panel to reach consensus about a particular field of interest. The basic Delphi design includes three main features: anonymous response, iteration and controlled feedback, and statistical group response [29].

For finding our panel we consulted, the Innovation Partnership AAL (ipAAL) which was established by the German Ministry of Education and Research (BMBF) and the Association for Electrical Engineering, Electronics and Information Technology (VDE) in 2009 to promote AAL research. The ipAAL has established working groups, congresses, and a mailing list with more than 1800 interdisciplinary list members.

We modified the traditional Delphi method in so far, that we did not start with a small expert panel. We needed for our research AAL experts which represent the multidisciplinarity of the field. Therefore, we decided to collect major issues in the first round from a broad interdisciplinary group to achieve a high degree of comprehensiveness in a qualitative approach. The ipAALs mailing list was chosen as panel for the first round.

We used consistent group response [30] as stopping criterion for the questioning.

The design and methods of our survey are shown in ▶Figure 1. The first round of the survey was qualitative (brainstorming). We formulated four questions under investigation to be answered as free text statements [31]:

- What potential does IT in the AAL context has from your point of view? (potential)
- Which objectives do you consider most important for IT in the AAL context? (objectives)
- What requirements have to be fulfilled by IT in the context of AAL? (requirements)

- Which further research is needed from your point of view? (research needs)

Additionally, we asked for structured information about demographics (e.g. age) or experience with AAL projects. To better understand how our expert panel is composed, we asked for the kind of institution the participants work for and the role they have with respect to AAL (consulting, financing, research, provider, developer, consumer, customer, or 'other'; multiple answers allowed).

Qualitative content analysis was performed for all statements mentioned by survey participants. Two of the authors (KS and PK) analyzed, categorized, and summarized the statements independently according to the concept of inductive item development [32]. The results of this process were compared and we agreed on harmonized items. It is recommended by Mayring [32] to formulate categories and items in terms of the material. Thus, we defined four categories of items in analogy to our questions under investigation: potential, objectives, requirements and research needs (s. above).

We used the items in the categories to build the questionnaire for the second round. This questionnaire also served as feedback for the participants of our survey. The items in the questionnaire were clustered with regard to content.

The items in the second round were rated by the participants on a 5-point Likert scale according to their importance ('1' equivalent to 'unimportant', '5' equivalent to 'very important'). Since we expected it might be more comfortable for participants to fill in this quantitative survey than the qualitative of the first round, we sent the call for participation again to the whole ipAAL mailing list. We regard the participants who participated in the second round as the Delphi studies' expert panel.

For the quantitative analysis of the three rounds, we conducted descriptive statistics. We summarized continuous data by using means with standard deviations (SD), medians with inter-quartile ranges (IQR), and minimum and maximum. After the second round, we used exploratory factor analysis [33] with principal components extraction and varimax (orthogonal) rotation to identify the underlying component structure. Items with low factor loadings of < .45 were removed. Internal consistency of the obtained scales was evaluated by means of Cronbach's Alpha.

The results of the third round were examined for differences between age groups and project experience using analysis of variance (ANOVA) with Tukey post-hoc tests [34].

Finally, we compared answers from the second and third round and performed a paired *t*-test to investigate whether the feedback after the second round had influenced the assessment of the items in the last round. Because this was an exploratory analysis, the significance level was set to 5% (two-sided) without any adjustment for multiple testing. All statistical analyses were carried out with IBM SPSS Statistics version 18 [35].

We realized an online questionnaire with the electronic survey system LimeSurvey [36]. Since no login to the system was required, anonymity was possible.

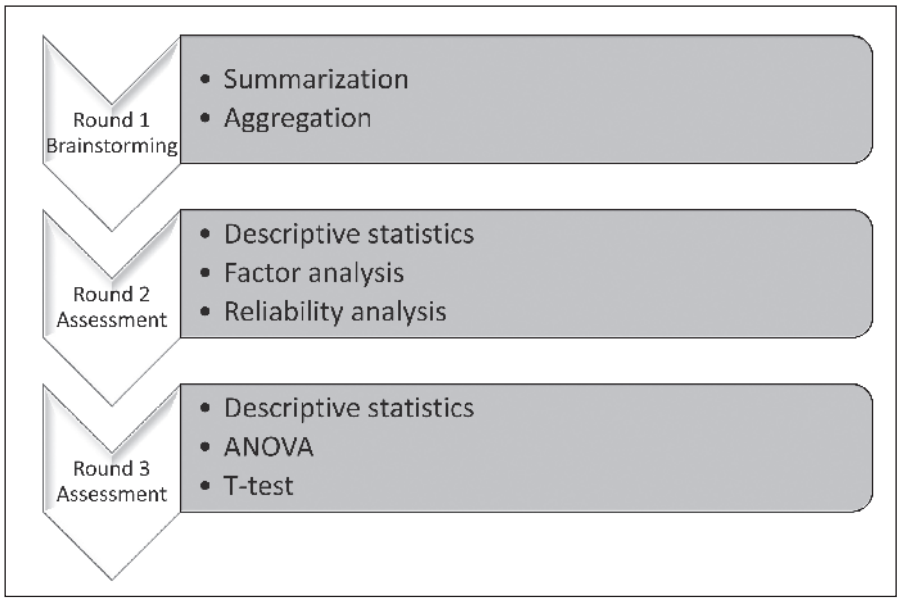

Figure 1 Design and methods of our Delphi survey. The results of the first round were qualitative and the summarization and aggregation led to items. The second and third round were quantitative assessment of items.

3. Results

3.1 Round 1

In the first round 81 participants answered the questionnaire giving 766 statements. Participants were relatively uniformly distributed among research (28%), development (22%), and counseling (24%). The complete distribution is shown in ▶Table 1.

The most relevant topics due to frequency of mentioning were

- ease of use and barrier free design,
- interoperability of components,
- and user needs and expectations.

Several items occurred in more than one category. When we reduced this overlap the category 'objectives' became dispensable. Eventually, inductive item development resulted in 28 items in the category 'potential', 45 related in the category 'requirements', and 22 related in the category 'research needs', which were used for building the questionnaire of the second round. Examples for three of these items are simplicity, interoperability and user requirements, derived from the frequently mentioned topics above.

In the category 'requirements' we identified eight items which can be regarded as

AAL-Role	Round 1	Round 3
Consultation	33 (24%)	31 (26%)
Financing	1 (1%)	2 (2%)
Research	38 (28%)	34 (27%)
Provider	12 (9%)	9 (8%)
Development	31 (22%)	24 (20%)
User	11 (8%)	6 (5%)
Purchaser	6 (4%)	5 (4%)
Others	6 (4%)	8 (8%)
Total	**138 (100%)**	**120 (100%)**

Table 1 Role of participants with respect to AAL in round 1 and round 3 (multiple answers allowed)

common requirements and which are a prerequisite for all AAL technology, independent of the kind of technology and application area: 'functional and system reliability', 'robustness', 'safeguarding against failure and availability', 'data security', 'consideration of data privacy issues', 'resolve legal issues, especially liability', 'consideration of moral / ethical requirements', and 'easy installation and configuration'.

3.2 Round 2

The results of this round are based on 173 responses. The items of all categories have been consistently rated between 3 and 5 (1 equivalent to 'unimportant', 5 equivalent to 'very important'). There was no rating below 3. The means of items in the category 'potential' ranged between 3.2 and 4.1, in the category 'requirements' between 3.3 and 4.7, and in the category 'research needs' between 3.4 and 4.4. Since none of the items was considered unimportant, the amount of items for the third round could not be reduced this way.

Exploratory factor analysis was done within each of the three categories. This process reduced the 95-item list to a 91-item list that measured 9 components in category 'potential' explaining 66.4% of the variance, 13 components in category 'requirements' explaining 72.4% variance, and 5 components in category 'research needs' explaining 61.4% variance. The online questionnaire was adapted accordingly. The items in the questionnaire for the third round were grouped according to the results of the factor analysis.

The results of this round were presented graphically, indicating the mean and standard deviation for each item. We summarized the methods used and the reduction of items in the feedback to the participants.

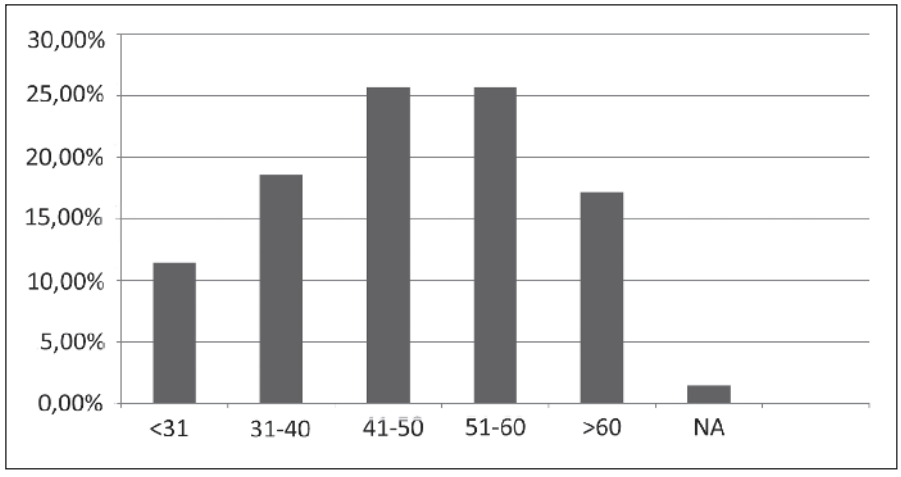

Figure 2 Age distribution of participants in round 3

3.3 Round 3

From 173 respondents of the second round 141 agreed to participate in the third round. Seventy of them actually returned the questionnaire. The distribution of the stakeholders in this round was: consultancy (26%), development (20%), and research (27%). ▶Table 1 shows a comparison of the distribution in the first and third round. Of the persons participating in the survey, 11% were below the age of 31, 19% between 31 and 40, 26% between 41 and 50, 26% between 51 and 60, and 17% above the age of 60 (▶Figure 2). Of the participants, 29% stated to have taken part in a general AAL project, 41% in an AAL IT project, 23% did not work on an AAL project yet, and 7% did not answer this question.

The rating of the importance of the individual items in all categories was similar to the second round: Means of the assessment of items in category 'potential' were: 3.3 to 4.4; in category 'requirements': 3.4 to 4.7; and in category 'research needs': 3.3 to 4.6. Therefore, the stopping criterion of consistent group response was reached after three rounds.

In the category 'potential', items describing informal caregiving and health care were assessed especially high:

- 'telemedicine and telecare even in rural areas' with a mean assessment of 4.39,
- 'support for caring relatives, especially if they work or live far away' with mean 4.36,
- 'relieve nurses of routine activities that do not involve patient contact (e.g. documentation)' with mean 4.23.

The lowest assessment in the category 'potential' was 'increase degree of process automation' with mean 3.28.

In the category 'requirements', items related to user-friendliness dominated the ranking. Top five of this list were

- 'early involvement of users (patient, family members, service providers, etc.) in the development process of IT solutions' with a mean assessment of 4.73
- 'maintain or increase the independence of users' with mean 4.73,
- 'high usability for patients with multiple diseases' with mean 4.72,

- 'consider the demand and the needs of the elderly' with mean 4.70,
- 'intuitive use (also for cognitively impaired and / or users with low technologic literacy)' with mean 4.69.

The least important item with a high variability was 'open source'(mean 3.44).

In the category 'research needs', the top rankings represented different directions of research. The highest assessments were for

- 'user-friendliness' with a mean assessment of 4.58,
- 'definition of an acceptable level of data protection and data security' with mean 4.42,
- 'development of business processes and models considering user needs' with mean 4.29.

An analysis excluding all participants which do not have any experience with AAL-projects had hardly any influence on the ranking. ▶Table 2 lists the assessment results for items which were identified as common requirements for all AAL applications, independent of particular technology or application areas.

The complete results of all categories and their ranking can be viewed in ▶supplementary material published on www.methods-online.com.

One way ANOVA of the five age groups found no significant differences in the assessment of the items in the category 'potential'. In the category 'research needs' four items had a significantly different assessment in two age groups: 'evaluation studies', 'propagation and diffusion of existing project solution', 'appropriate involvement of relatives/working in honorary capacities' and 'scalability'. Post-hoc analysis was not performed.

Significant age differences observed in the assessment of the items in the category 'requirements' were: 'unobtrusiveness and invisibility of the technology' ($p = 0.028$), 'expansibility, individual tool set' ($p = 0.044$), 'low resource requirements' ($p = 0.021$) and 'consideration of unclear data quality' ($p = 0.039$). Post-hoc analysis showed that the first three items mentioned were rated as more important by the groups '51 to 60 years' as by the group 'under 31'. 'Consideration of unclear data quality' was rated higher by the group '41 to 50 years' than by the group '31 to 40 years'.

Table 2 Assessment of common requirements for AAL technology in round 3

Requirements	Mean	Standard deviation
Functional and system reliability	4.585	0.583
Robustness	4.556	0.616
Safeguarding against failure and availability	4.545	0.612
Data security	4.484	0.846
Consideration of data privacy issues	4.424	0.912
Resolve legal issues, especially liability	4.394	0.892
Consideration of moral / ethical requirements	4.242	1.068
Easy installation and configuration	4.138	0.864

One way ANOVA of the experience with AAL projects found several significant differences in the assessment of items among the groups without any AAL project experience, with AAL-IT project experience and AAL project experience in general. The results are summarized in ▶Table 3.

We analysed with paired t-test, whether the items were differently assessed in round 3 after receiving feedback of the results of round 2. No significant differences between the two rounds were found in the

Table 3 Significant pairwise differences in the assessment of items with respect to AAL project experience. Significant differences between two groups are represented by arrows : ↑ for the group which rated the item significantly higher on average and ↓ for lower ranking. No arrow means that no significant difference was observed between this group and the others.

Category	Item	No AAL project experience	AAL-project experience in general	AAL-IT project experience
Potential	Avoid redundant data collection in health care	↑		↓
Potential	Higher efficiency, effectiveness and safety in medical applications	↑		↓
Research needs	Propagation and diffusion of existing project solution	↑		↓
Research needs	Algorithms for early detection of age-related diseases		↓	↑
Requirements	Easy integration into existing infrastructure	↑		↓
Requirements	Not discriminating elderly	↑		↓
Requirements	Same user interface for different modules	↑		↓
Requirements	Low resource requirements	↑		↓
Requirements	Reimbursement, e.g. by health insurance	↑		↓
Requirements	Open source		↑	↓
Requirements	Emergency concept if component fails		↑	↓
Requirements	Easy to maintain		↑	↓

category 'requirements'. In the category 'potential', we found significant differences in 10 of 28 items, e.g. 'expand the social network of AAL-users and easier maintenance of contacts' ($p = 0.001$), 'relieve nurses of routine activities that do not involve patient contact (e.g. documentation)' ($p = 0.041$) or 'networking different actors like service provider or health care provider' ($p = 0.002$), which were rated higher in the third round. Only the item 'individualization of health care, nursing and medical treatment' ($p = 0.030$) was rated lower. In the category 'research needs', the item 'medical evaluation of everyday life sensors (e.g. light switches)' was rated significantly higher than before.

4. Discussion

4.1 Discussion of Results

As a result of our survey, we generated three lists of highly relevant items for IT research in the AAL context. In the category 'potential' items are listed, that hold the ability or capacity for bringing AAL solutions into being or enhancing their sustainability. In the category 'research needs' major topics of IT research for improving AAL solutions are listed.

In the category 'requirements' we have identified eight items that are common requirements for all AAL projects and applications (▶Table 2). Each project or AAL component has to fulfill these requirements independent of the used technology or the application area. The remaining requirements apply for particular applications or have a varying relevance in different contexts. E.g. an 'emergency concept when a component fails' is less important if a component is only used for comfort purposes as it would be if it was used for medical issues. Legal issues have to be fulfilled in any case.

The complete list of requirements from our Delphi survey can be used in upcoming AAL projects as framework. Each project should carefully analyze whether the common requirements (▶Table 2) can be fulfilled. The remaining requirements which are not applicable for all AAL projects can be used as a reference catalogue for rating the importance of each item for success and sustainability of the planned project.

High assessments have been given to nearly all items in all three categories. The factor analysis in round 2 has hardly reduced the number of relevant items. This reconfirms the interdisciplinary nature of the field AAL and the difficulty of identifying priorities for certain research efforts. Regarding the category 'potential' a cluster of items with an especially high ranking can be identified representing medical issues, i.e. the field of health care is expected to benefit considerably from IT solutions for AAL. In the categories 'requirements' and 'research needs' as most prominent cluster 'user optimization' could be identified.

We used structured data for describing how our panel participating in the survey was composed. The results show, that it was possible to include people with different background to our study.

The comparison among the age groups showed, that features like unobtrusiveness, expansibility and low resource requirements are more important for the elderly generation.

Most interestingly several items were rated significantly lower by the group of respondents who already participated in an AAL-IT project. An exception is the development of algorithms for early detection of age-related diseases, which is seen as a major challenge to them. Nevertheless, an analysis excluding respondents which do not have any AAL project experience did not lead to a different order in rating the importance of the items.

A comparison between the assessment of the second and the third round showed few changes of the assessment in the categories 'requirements' and 'research needs', but several significant differences in in the category 'potential'. In all cases but one the items were rated higher in the third round. An explanation for this effect could be that the feedback of the second round led to a higher awareness of the potential of IT for AAL solutions, but it cannot be excluded that especially people with a high awareness of this potential answered the questionnaire of the third round.

4.2 Related Approaches

The broad variety of identified requirements and research needs is in accordance with the results of EU projects like FUTURAGE and BRAID which took place in parallel to our survey. They were stronger focused on the elaboration of research agendas and were not limited to German participants.

FUTURAGE emphasizes user engagement in implementation and new multidisciplinary approaches. This corresponds with the results in our survey, where items that describe user requirements or appropriateness according user needs got a high assessment.

FUTURAGE regards ICT as an important tool e.g. in informal caregiving or social inclusion and formulates research questions like "What is the role of ICT-based solutions in improving the quality of long-term care provided by informal carers, as well as their quality of life?". Our Delphi study reveals requirements that have to be regarded in the design of such ICT-based solutions so that they can contribute to improving quality of care and life.

In contrast to FUTURAGE which is on aging research in general, the BRAID project focuses on ICT like our Delphi survey. BRAID research actions are segmented in the areas 'independent living', 'health and care in life', 'occupation in life', 'recreation in life' and a more general group. The aim of our Delphi study was to identify important IT issues that can be applied in different areas independent of a particular technology. Results can be used in several future research actions.

4.3 Limitations of the Study

Delphi surveys have proven as validated research tools that have been successfully applied in different research areas [37], including medical research areas [38] and primary care [39].

When we started our Delphi study are clear analysis of the field AAL was still lacking. The idea of our survey was to better understand major IT challenges and to highlight the potential arising from generic medical informatics solutions. Therefore, it is on one hand a limitation of the

study, that we did not structure the study according a segmentation of the field AAL, but it might be also a strengths that the results are not limited to certain application areas.

The absolute number of participants in our survey is comparable to other Delphi studies [30, 40, 41]. Nevertheless, the response rate appears to rather low. This might have different reasons: First of all, participation was voluntary and without compensation. Subscribers to the mailing list were highly interdisciplinary, what was explicitely intended by us. Several list members might have not felt comfortable with formulating and assessing IT research needs and requirements. In the second round the return rate was doubled by providing items which had to be assessed, although the number of items was rather high. Therefore we assume that the open-ended questions in the first round were an obstacle for answering the questionnaire. Nevertheless, high response rates are not necessarily regarded as a prerequisite of a valid survey [42].

4.4 Perspective

Since such a high amount of items has been rated high in our Delphi survey further research is necessary to utilize the results for particular applications. The list of requirements resulting from our Delphi study has to be elaborated in further detail to serve as an effective framework for future projects. For operationalizing the list of common requirements existing laws, directives and standards should be identified and regularly updated. Criteria have to be developed for all requirements that can measure if the requirements are fulfilled in a particular project. This can lead to a framework and to the development of supporting tools, which help to customize the framework to a particular application.

5. Conclusions

A wide variety of IT issues have been regarded as important for AAL by participants of our Delphi survey. A high potential for IT complementing AAL solutions is seen. Since medicine and health care is seen as an application area with major potential for AAL medical informatics and AAL research should work closely together. A lot of IT challenges for AAL like early involvement of users, emergency concept if component fails, data privacy and expansibility are well known in the medical informatics community. Experiences and results from medical informatics research can be transferred to strengthen AAL research, for example eHealth solutions and knowledge-based decision support.

When we regard the extensive list of requirements, it becomes obvious that it is not efficient to develop dedicated solutions for individual projects but to provide generic methods and reusable components. Common requirements like robustness, reliability, legal and ethical issues are mandatory for AAL application, otherwise technology and systems are not sustainable. Further requirements are dependent on the context of use and our list of requirements can be used to decide on priorities for particular projects.

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