Automated Engineering for Health Smart Homes: Find a Way in the Jungle of Assistance Systems

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Abstract. Health Smart Homes are a promising part of digital personalized health care. However, engineering of the underlying residential assistance systems is a complex process that needs to be supported by computer-based design tools. This paper presents a formal definition for the engineering task and proposes a methodology for model-driven design process automation, that is implemented in a web-based pilot application. Using this approach for design support, the challenge to efficiently compose personalized assistance systems for patients can be coped with in the future, which reduces a major barrier for smart home assistance applications.

Keywords. Ambient Assisted Living, Health Smart Home, Digital Personalized Health, Interoperability, Telemedicine, Telehealth

1. Introduction

As a promising part of digital personalized health care, *Health Smart Homes* (HSH) [1,2] combine concepts from Smart Home, Ambient Assisted Living (AAL), and Telemedicine [3], aiming to improve the quality of health care delivery [4, 5]. Yet, a significant proliferation of HSH technology into real-world applications is still missing [6, 7], largely due to ineffectiveness of system design [8]. The range of available assistance components is overwhelming and these components are not always compatible with each other [4, 9]. Even professional planners are not able to chart the area of assistance solutions comprehensively, as they can only be familiar with a small number of components. Thus, engineers, patients and health care providers are tangled up in navigating the confusing "jungle" of assistance solutions. They require support for component selection and composition in order to tailor assistance systems to patient needs.

We envision an automated design approach that takes patient requirements and needs into account and identifies several suggestions that each fulfill the patient's individual demand for technical support [9]. As a prerequisite for this vision, this paper presents a formal definition for the engineering task and proposes a methodology for model-driven design process automation.

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The remainder of the paper is structured as follows: The next section infers requirements for a design methodology and discusses related work for HSH engineering. The proposed new methodology is presented in Section 3, after introducing a formal problem definition for the engineering task. Section 4 discusses the methodology based on a pilot application. Finally, Section 5 summarizes the paper and provides further research areas.

2. Related Work

A design methodology needs to meet the following requirements: *Req.* A) *Efficiency and Sustainability* allows the methodology to incorporate the re-use of existing components. *Req.* B) *Allowing for individual Customizability* states that fine-grained customization capabilities are required [1, 10]. Since manually exploring the design space is not feasible due to a large number of potential solutions, *Req.* C) *Capability of Automation* demands the automation of key processing steps of the design methodology. Considering the variety of possible solutions, determining the most suitable solution will involve multiple criteria (such as costs, installation and maintenance effort). Thus, *Req.* D) *Multiple Solutions* states that a design methodology needs to be able to offer a "design space" containing possible alternative designs [11].

Nowadays, HSH systems are often developed from scratch as monolithic systems (*one-off approach*) [6, 12], applying generic high-level methodologies such as model-driven approaches (MDA). While this allows for a precise customization, these approaches become inefficient [11] as they incur an high effort for system design. Alternatively, HSH are sometimes designed based on coarse-grain bundles of existing modular components (*bundle approach*) [10], in an attempt to achieve a rudimentary level of customization with lower design effort. However, given the diversity of assistance solutions [9], the bundle approach does not allow a sufficiently fine-grained customization. *Integration-focused approaches* rely on standardization of data exchange, integration frameworks or plug-and-play mechanisms when composing systems from components-off-the-shelf [6]. Yet, while this reduces interoperability issues [1], selection of components and communication planning still needs to be done manually.

As a consequence, there is a need for a new methodology that is capable of fulfilling *Req.* A) to D), especially providing individual customization capabilities in combination with an efficient design approach.

3. Automated Engineering of Health Smart Homes

3.1. Formal Task Definition

The task in HSH engineering is to design a suitable assistance system by selecting and composing assistance components to *Candidate Solutions* HSH_{cand} in order to meet the set of requirements posed by the HSH occupant (*Condition Portfolio* HSH_{req}). The design process builds upon a *Knowledge Base* HSH_{KB} containing the vocabularies of user requirements, assistance functions and assistance components [13] as well as their interdependencies. This task description can be formalized as follows:

Definition 1 ***Knowledge Base:*** *Let be:* (i) *$\hat{R}$ the universal set of user requirements;* (ii) *$\hat{F}$ the universal set of assistance functionality;* (iii) *$\hat{C}$ the universal set of assistance components;* (iv) *$\hat{T}$ the universal set of semantic types of the information exchangeable by assistance components;* (v) *$R_f \subseteq \hat{R}$ the set of user requirements satisfied by each assistance functionality $f \in \hat{F}$;* (vi) *$F_c \subseteq \hat{F}$ one set of realized assistance functions for each assistance component $c \in \hat{C}$;* (vii) *then the* knowledge base for HSH design *is defined as $HSH_{KB} = (\hat{R}, \hat{F}, \hat{C}, \hat{T}, \bigcup R_f, \bigcup F_c)^2$.*

Definition 2 ***Condition Portfolio:*** *The patient's* condition portfolio *is defined as a subset R of user requirements s. t. $HSH_{req} = R \subseteq \hat{R}$.*

Definition 3 ***Candidate Solution:*** *Let be:* (i) *C the multi set of selected assistance components, with $\forall c \in C : c \in \hat{C}$;* (ii) *$B$ the multi set of bindings (i. e. communication relations) modeling the information exchange between assistance components, with each binding $b = (c_o, c_i, T) \in B$ defined by the tuple of the information output and input components c_o and c_i, and the set $T \subseteq \hat{T}$ of information types of the exchanged data;* (iii) *then a* candidate solution of a HSH *is defined as $HSH_{cand} = (C, B)$.*

Definition 4 ***HSH Engineering Task:*** *Given the input of:* (i) *HSH_{KB} a knowledge base for HSH engineering and* (ii) *HSH_{req} a specific patient condition portfolio, the goal of the* HSH engineering task *is to find the set $\mathscr{C}$ of valid candidate solutions HSH_{cand} with validity of a candidate solution $HSH_{cand} = (C, B) \in \mathscr{C}$ meaning that all patient requirements are met by the candidate solution: $R \subseteq \bigcup_{c \in C} \bigcup_{f \in F_c} R_f$.*

3.2. Engineering Methodology for Health Smart Homes

Following the MDA paradigm to abstract from technology-specific information, we propose to add an additional technology-independent intermediate layer. As can be seen from the equation in Def. 4, when determining the validity of the candidate solutions, an intermediate step is taken to relate assistance components C to the requirements R. In accordance to this observation, a suitable intermediate model layer consists of an information flow graph containing technology-independent assistance functions F:

Definition 5 ***HSH System Specification:*** *Let be:* (i) *F the multi set of required assistance functionality, with $\forall f \in F : f \in \hat{F}$;* (ii) *$L$ the multi set of links modeling the information exchange between assistance functions, with each link $l = (f_o, f_i, T) \in L$ defined by the tuple of the information output and input functions f_o and f_i, and the set $T \subseteq \hat{T}$ of abstract information types of the exchanged information;* (iii) *then a* system specification for HSH *is defined as $HSH_{spec} = (F, L)$.*

With the introduction of the intermediate model layer HSH_{spec} , the design task can be split into *Step 1) Computation of HSH system specification*, which yields technology- and vendor-neutral formalized specifications for the HSH, and *Step 2) Materializing the specification with assistance components*, which in turn yields several design suggestions (Figure 1). The different design alternatives may now be inspected in order to determine the most promising design proposition. As this depends on planner's experience and

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[2] For readability we do not write the index for unions/sums that are unambiguous, i. e. $\bigcup F_c = \bigcup_{c \in \hat{C}} F_c$.

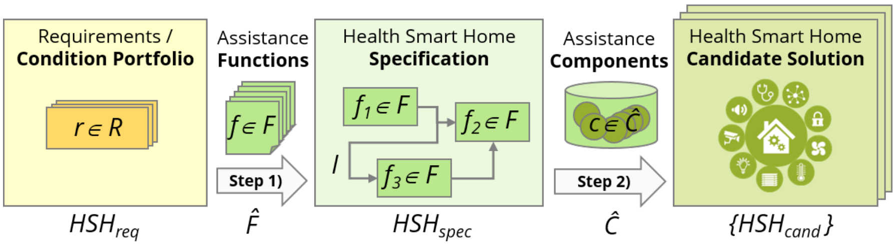

Figure 1. HSH engineering task and methodology of Automated Design for HSH

involves assessing additional criteria (e. g. costs) not modeled here and the decision may be rooted in the planner's experience, making the final decision is out of scope of this methodology and needs to be made in close collaboration with the patient.

4. Prototype and Discussion

To show the feasibility of the methodology, a pilot application has been implemented as a web-based suggestion system for AAL counselors, intended to facilitate the design and tailoring process of HSH solutions during patient consultation. After an interview-style analysis of user requirements, appropriate assistance functionality is determined. Finally, suitable assistance components are suggested to the AAL counselor and patient.

By composing existing assistance components based on their functionality, the presented methodology is able to efficiently provide several system proposals without the need for labor-intensively developing assistance systems from scratch. It therefore meets *Req.* A) *Efficiency and Sustainability*. Since the methodology is based on formal sets of user requirements, assistance functions and assistance component functionality, it can be supported by computer-based tools, fulfilling *Req.* C) *Capability of Automation*. The application of computer-based tools furthermore allows for an efficient exploration of the design space. The methodology is thus able to meet *Req.* D) *Multiple Solutions*. Finally, the input for the proposed design process is not confined to a fixed set of coarse patient types, but rather features a detailed vocabulary $\hat{R}$ of possible user requirements and patient conditions, which in the pilot application have been identified according to personas and insights of health care providers. Thus, a fine-grained customization of the assistance systems is possible, fulfilling *Req.* B) *Allowing for individual Customizability*. Compared to the engineering methods *one-off* and *bundle* approach discussed in Section 2, the proposed methodology allows for an efficient exploration of the design space, thus lowering the overall costs of HSH engineering. Subsequently, *integration-focused* approaches can be applied for realization of the selected system design.

5. Conclusion

One major barrier for the proliferation of assistance systems in the context of smart homes is the tedious and ineffective design process. This paper proposed a model-based methodology for the automated engineering of HSH, enabling re-use of existing assistance components as well as fine-grained customization of the resulting assistance systems. By splitting the design task introducing a technology-neutral intermediate layer for system specification, the overall engineering task becomes more manageable and an abstraction from technology-specific information can be achieved.

Next steps include a further investigation into functional component models to ensure that the broad variety of real-world assistance functionality can be adequately modeled. Similarly, refining the universal set $\hat{R}$ as well as optimizing the algorithm for design candidate identification are important tasks. Finally, tool-support for the actual process of functional component modeling shall reduce the impediments for component manufacturers to provide high-quality functional component models.

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