Co-Creating Emotionally Aligned Smart Homes Using Social Psychological Modeling

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ABSTRACT

Smart homes have long been proposed as a viable mechanism to promote independent living for older adults in the home environment. Despite tremendous progress on the technology front, there has been limited uptake by end-users. A critical barrier to the adoption of smart home technology by older adults is the lack of engagement of end-users in the development process and the resulting one-size-fits-all solutions that fail to recognize the specific needs of the older adult demographic. In this paper, we propose a novel online platform aimed at closing the gap between older adults and technology developers: ASPIRE (Alignment of Social Personas in Inclusive Research Engagement). ASPIRE is an online collaborative network (OCN) that allows older adults, care partners, and developers to engage in the design and development of a joint shared product: the smart-home solution. To promote the adoption of the OCN and the alignment of this collaborative network with the values and emotional needs of its end-users, ASPIRE harnesses a social-psychological theory of identity. This paper presents ASPIRE as a conceptual model, with a preliminary implementation.

CCS Concepts

•Human-centered computing → **Ambient intelligence; Collaborative and social computing; •Applied computing** → **Health care information systems; •Computing methodologies** → *Knowledge representation and reasoning;*

Author Keywords

Alzheimer's; Online Collaborative Networks; Affect Control Theory; Co-Design; Participatory Design; User-Centered Design; Hierarchical Task Network.

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INTRODUCTION

The rising tide of individuals living with memory loss and other forms of cognitive impairment represents an important societal challenge. While "aging in place", or in one's home, is desirable on many levels, it is difficult to ensure the safety and well-being of older adults as they start experiencing symptoms associated with dementia while limiting the burden on their care partners. Technology is increasingly viewed as a potential tool to facilitate aging in place.

Several research projects in pervasive computing have demonstrated the ability to assist the completion of complex Activities of Daily Living (ADLs), for example with cognitive reminders, functional aids, and ambient emotional palliations [28, 20, 2]. These technologies couple sophisticated sensing devices for the measurement of physiological, emotional, and functional states of humans, with artificial intelligence and machine learning systems that reason about situations and take decisions, and use human-computer interaction (HCI) methods to design appropriate feedback. In addition, some projects have explored how intelligent systems could be customized and easily installed in homes [6], and how artificially intelligent controllers could be specified by end users directly to allow these smart objects to be used in assistive technologies [11]. A key consideration in the development of these types of assistive technologies is that cognitive impairments will impact a variety of ADLs differently depending on individual variations and context. Due to this heterogeneity, customization is necessary in a deployment so that an individual's particular needs are appropriately addressed.

Despite the potential advantages of pervasive and/or intelligent assistive technologies for aging-in-place, many attempts to develop and implement real world applications have failed to become widely adopted. One key barrier in the adoption of these technologies may be a lack of socio-emotional alignment. Studies have found that identity changes dramatically over the course of disease progression [22] and that persons with dementia often have more vague or abstract notions of their self-identity [24] than do non-afflicted persons. As such, products that do not deeply embed social and emotional intelligence may not be aligned with the needs and values of target end-users, thereby limiting their use.

To address the challenges of smart home development for an older adult population in a way that recognizes the need for emotional alignment in technology, we conceptualized the ASPIRE (Alignment of Social Personas in Inclusive Research Engagement) platform. ASPIRE is an online collaborative network (OCN) that allows older adults and developers to engage in the development of a joint shared product: the smart-home solution aimed at addressing the specific needs of older adults. The platform runs in a web browser and allows multiple, geographically distributed people to connect and collaborate on a single task (in the present case, designing and implementing a smart home). ASPIRE maps specific smart-home use cases to a knowledge base that represents tasks requiring assistance in the home as a hierarchical task network (HTN). The OCN also integrates ideas of social and emotional alignment by populating a model of identity that tailors assistance on an emotional level.

In the following sections, we provide an overview of the key components of ASPIRE from a high level. We review affect control theory, identity in Alzheimer's, online collaborative networks, hierarchical task networks, emotional control mechanisms, and the hardware (sensors/effectors/middleware) that we use in the smart-home deployment. We then describe the overall ASPIRE workflow with a sample use case scenario.

METHODS

Affect Control Theory

ACT posits that interactions are guided by a psychological need to maximize the consistency between culturally shared *fundamental sentiments* about identities and behaviours, and the situationally created *transient impressions* about identities and behaviours in real-time interactions. Alignment between an individual's perceived identity and the social context is likely driven more by implicit, affective processes than by conscious thought [8, 25]. This alignment principle is a powerful predictor of human behaviour [18], in domains including health and illness [17]. Fundamental sentiments and transient impressions are interpretations of social objects, such as interactants' identities and behaviours, represented as vectors in a 3D affective space [23]. The basis vectors of the affective space correspond to feelings of Evaluation/valence, Potency/control, and Activity/arousal (EPA). Emotions in ACT have a clear definition. They are the vector differences between fundamental sentiments and transient impressions, and are used as signals of this difference to interaction partners in order to promote or restore alignment and consistency.

Crucial to the affective alignment proposed by ACT is the notion of identity: who a person believes they are in a given social context. Identities in ACT refer to situational roles that a person takes on when interacting with others. Thus, in a professional context, when managing employees, a person may select an identity of "boss" with an associated sentiment that is slightly good, quite powerful, and somewhat active. ACT also explains a person's overall sense of self as a synthesis or combination of many different identities that are regularly enacted [19]. This combination is referred to as the *persona*, and the associated sentiment as the *self-sentiment*. Thus, the "boss" may also be a "father", a "husband", and "musician" for example. When moved to a long-term care facility, an older adult may have an identity of "patient" implied by their new institutional setting. Identity profiles of concepts such as "boss" and "patient" can be measured by rating affective meanings of concepts on numerical scales [9]. Alignment of identities has been proposed to facilitate the adoption of smart home technology in older adults [16].

A generalization of ACT has been proposed, called *BayesACT*, that models uncertainty in identities, can learn about identities, and take actions that are simultaneously goal-directed and affect-sensitive [12]. *BayesACT* is chosen for this application over more commonly used *appraisal* theories of emotion, as it explicitly models change and uncertainty in identity (a hallmark of Alzheimer's), and relies less exclusively on higher-level cognitive processes (e.g. goal and intention analysis), which are less well preserved in Alzheimer's disease.

Understanding Identity in Alzheimer's Disease

In order to implement an ACT-based emotional module in ASPIRE, a deep understanding of identity and identity sentiments in Alzheimer's disease is required. Recent work used a qualitative process [14], in which 12 older adult care home residents and 12 care partners were interviewed. The interview covered life domains (family and origin, occupation/vocation, personal history and relationships), and feelings related to a virtual intelligent assistant. All interviews are transcribed and analyzed to extract a set of affective identities, coded according to the social-psychological principles of ACT. Results of the analysis show that a set of identities can be extracted for each participant (e.g., father, husband). Furthermore, results from this study provide support for the proposition that, while identities grounded in denotative memories fade as a person loses their ability to remember people and events, affective aspects of identity in the self-sentiment may persist longer, even without situational context [4].

Based on these long-form interviews, we have developed a short-form version which is used in the OCN to gather identity data. The identities thus gathered are then used to initialize the ACT-based model of emotions as described further the Emotional Control Module section.

Online Collaborative Networks

Development of social networking tools for older adults with and without dementia started with seminal early work on digital family portraits [21], reminiscence aids, and has moved to specialized devices focused on social connectedness through technology [1, 3]. There has, however, been little work on socially and emotionally aware tools allowing persons with dementia to collaborate on artifacts directly related to technology development.

Implementing ACT in online, social networking requires the consideration of socio-emotional alignment in group dynamics. ACT has been used to model interactions in small groups [10] by making explicit predictions about dominance and status structures based on identity and alignment. In the context of an OCN, ACT can be used to model and track behaviours on the platform, evaluate inclusiveness and engagement, and provide interventions (e.g., suggestions) to participants to level the playing field and include all members, particularly those with more difficulty in maintaining consistent identities or roles, such as is the case with older adults with dementia.

Hierarchical Task Networks

Effective smart homes should be able to monitor the progress of end users towards goals, and plan for future contingencies. To ensure the smart home solution effectively meets the needs of the older adult, two critical parameters must be considered. First, due to the limitations of sensors and to privacy concerns, not all attributes of physical objects can be measured. Thus smart homes should cope with partial observability due to missing or unreliable sensor data. Second, older adults with cognitive impairments are known to have increasing difficulty in the execution of ADLs, e.g. repeating and or mis-ordering steps [13]. Smart home solutions are required to identify these improper behaviors and provide assistance.

Given these two considerations, a smart home helping an older adult with cognitive impairments on their ADLs should address the following aspects: (1) tolerate partial observability caused by missing and unreliable sensors; (2) recognize concurrent goals; (3) detect improper steps and rectify the older adult from mistakes; and (4) present hints or prompts of various detail levels, such as desired next steps or higher level tasks. In this work, we adopt the hierarchical paradigm as defined in hierarchical task network (HTN) planning [7]. In HTN planning, high-level (composite) tasks are recursively decomposed into simpler subtasks by domain artifacts called methods. The decomposition process continues until so called primitive tasks, which represent concrete steps to execute, are obtained. Tasks and steps have preconditions that must be satisfied before they can be executed. Primitive steps are realized by the domain artifact operator. Hierarchical modeling such as HTNs are believed to be a natural representation for complex cognitive models.

With HTN, the goal recognition process is combined with the planning process to generate feasible next steps (or tasks) [26]. Partially ordered subtasks, alternative ways to achieve a goal, and preconditions of tasks and steps are considered thanks to the expressive power of HTN. When the algorithm is running, it tracks the ongoing goals, updates beliefs based on new observations, reports wrong steps, and presents prompt at different levels of detail. Issues like unreliable or missing sensors, concurrent goals, and wrong steps make the problem more difficult, and decrease the performance of the algorithm.

The HTN algorithm we have proposed was tested on simulated cases of different difficulties (e.g. missing sensors, wrongly executed steps, unreliable sensors). The algorithm works very well on simple cases, with accuracy close to 100%. Even for the hardest cases, the performance is acceptable when sensor reliabilities are above 0.95. Further, one of the main advantages for an HTN is that it is relatively easy to specify.

Emotional Control Module

The output of the HTN is a set of next steps to be taken by the user. Note that this "pending set" may contain steps from multiple, disparate goals. The final step for the smart home is to decide how to assist the user in completing one or more of these steps. While a naïve approach might select one that optimizes for completion (e.g the task with the fewest remaining steps), it still would not be able to select an assistance mechanism (e.g. a prompting style) that would be most effective for user uptake.

The goal of the Emotional Control Module (ECM) is to decide which of the steps (if any) to prompt for, and how to deliver the prompt in a way that best respects the end user's sense of self and current emotional state. Using a ACT-based model of identity, the next steps to take are evaluated for emotional alignment and the best one is chosen. For example, suppose the older adult is currently enacting his identity of "boss", and is therefore in a powerful and active state. Suppose that, in this state, he has two steps pending: calling the gardener to tell him to come and trim the hedge, and taking his medication. The ECM may decide to opt for the first, as it fits with his sense of self and will reinforce his current feelings of independence and strength. The medication taking, which reminds him of his frailty, might be delayed to a slightly later time. The ECM runs independently of the HTN planning and goal recognition system, yet has a representation of each possible step and the possible effectors that could be used to guide the person through that step. There may be multiple effectors for a given step, each with a different emotional signature. For example, different prompts could be delivered in different voices (male vs. female, commanding vs. suggesting) [12].

Sensor Level Breakdown

One or more sensors must be assigned to each operator (leaf node) in the HTN. To assist with this assignment process, each room in the user's house is divided into four sublevels with at least one sensor assigned to each level. Sensors can be selected from each category that fit the HTN specification and the user needs. The first level requires having sensors attached to each entry point in the house. This will allow the system to recognize if a person has entered or left a room. The second level involves attaching sensors to utilities specific to each room, such as a bathroom sink or a bed, in order for the system to understand the user's activity in each room. The third level comprises of any sensors that are specific to the activity that the system is assisting with. Lastly, the fourth level requires having sensors attached to any devices that have been set as preconditions in the HTN that need to be satisfied before a step can be executed.

Effectors and prompting strategies

When selecting the most effective type of prompt to use in smart home systems, it is important to recognize that each user has a unique cognitive profile and as a result, each prompt needs to be chosen according to their specific needs. Although this is a highly personalized choice, there are certain constraints implied by the various cognitive deficits experienced by older adults which allow for a categorization of assistance strategies [15]. The categories include verbal, sound, music, textual, video and light, and are related to memory impairments, deficits in executive function, sensory problems, and others, through a decision tree. This tree is used to efficiently narrow down which prompt will be the most effective to guide the user through their task.

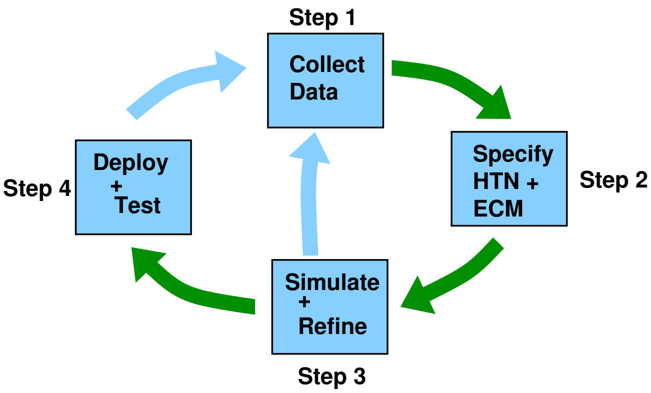

Figure 1. ASPIRE Workflow. Green (Dark) arrows denote specifications, blue (light) denote refinements.

Connecting sensors with effectors

The sensors and effectors are connected through a server using the XMPP protocol, which allows for ongoing live connections, fast sensor state reception, and reduced data transfer times and process overhead when compared to REST. There are essentially no middleware connecting devices, further reducing delays. Data to be stored is divided into two categories, event data and other. The event data, like sensor state changes, should be efficiently broadcasted immediately, and so is stored as no-SQL like data structure as a requirement of real time databases. The other data, like sensor information and object information, is required to be constantly fetched and queried, therefore are stored in an SQL database to increase query speed. To ensure data consistency, we developed a SQL - realtime hybrid database based on Google Firebase as event broadcaster. Google Firebase can synchronize state across multiple clients, and is a scalable solution that delivers real time messages with minimum delay. These features are useful for delivery to multiple clients running on different platforms, for example transmitting information about an older adult's activities to their care partner, sending runtime performance data logs to developers to analyze and improve algorithms, or even broadcasting help requests during emergency situations.

ASPIRE WORKFLOW

The workflow for smart-home specification follows four major steps at a high level, as shown in Figure 1.

Step 1: Data Collection

The OCN is used initially by the older adult and/or their care partner, and a technology "helper" (e.g. a biomedical engineer responsible for initial data collection). The helper and older adult connect through an online video-chat interface, as shown in Figure 2. The helper sees additional widgets that allow him or her to control what information is displayed to the older adult. Initially, only the video chat is used, after which a series of input widgets are introduced that allow for the collection of information, such as basic demographics, followed by the identity survey.

Once the older adult is familiar with the interface, a map of the home is introduced, as shown in Figure 3. The map allows the older adult and care partner to walk through the issues

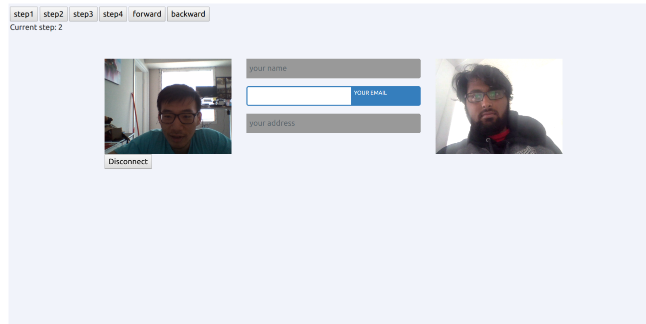

Figure 2. Initial Contact and data gathering. The "helper" is on the left, the care partner of the older adult on the right. The shared space in the middle shows the ongoing product the two are working on together.

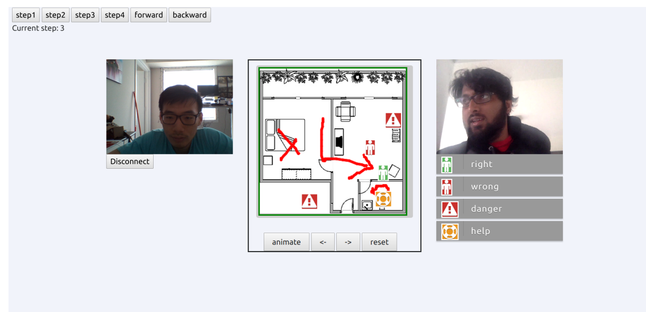

Figure 3. An interactive map of the home is introduced. The older adult or care partner can describe the use case by annotating the map.

they are having, describing these at a high level by drawing and annotating the map. This method serves two functions. First, it is relatively easy for someone to specify a use case in the home by acting it out (drawing on the map). Second, by engaging with a model version of their own home, they become partners in its development. This highly participatory user-centered co-design paradigm is fundamental to the long term adoption of the technology.

As an example use case, the care partner may demonstrate what happens at night when the older adult tries to locate the washroom. He or she may draw experienced patterns of movement on the map, and point to the locations of the bedroom and washroom. These trajectories are used in the subsequent step to generate a HTN controller for this specific use case. The care partner may add further information about the user's physical or mental state, such as that they don't have their hearing aid or glasses on, or that they are often agitated. This additional information is used to complement the existing social-psychological profile and to enhance and tailor the Emotional Control Module (ECM) for this case.

Step 2: Generation of HTN and ECM

The next step lies primarily with the helper, who takes the information gathered in Step 1, and populates the knowledge base for the HTN and the ECM. A simple interface is being developed, as shown in Figure 4. The helper is able to drag and drop each task, define its hierarchical order, preconditons and goals. General purpose situation models [27], ontologies [5] or behavioural analysis tools [11] may be useful here. The HTN is then converted into appropriate methods and operators

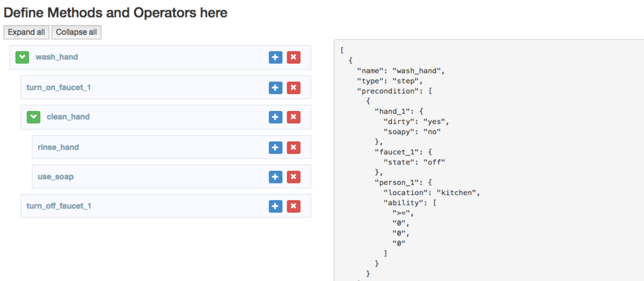

Figure 4. Interface for HTN specification. The ASPIRE helper can choose each task on the left, and verify the knowledge base on the right in JSON format.

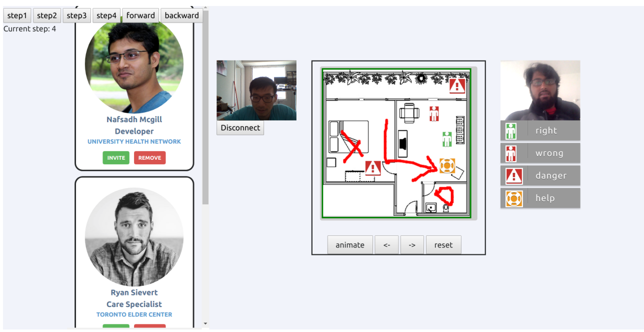

Figure 5. Introduction of other stakeholders.

in the HTN knowledge base, an example of which is shown in JSON format on the right in the figure. The helper also proposes a set of sensors and effectors by selecting from a sensor ontology. The helper may propose multiple sensors and effectors for each task. These will be refined with the end-user in the next step. Finally, the helper populates the ECM knowledge base, by specifying a set of identities and emotional states for the older adult in the use case.

Step 3: Simulation

In this step, the older adult is again engaged with the helper over the map (Figure 3), however this time the map is populated automatically using the developed HTN and ECM. The simulation shares the same communication infrastructure for deployment, so any runtime errors or execution delay will be captured, judged or improved. Sensors and effectors are proposed and evaluated by the end user, and discussion of potential side effects and best practices ensues, resulting in a final choice for a first implementation. This process may require multiple iterations back through Steps 1 and 2, allowing the older adult and care partner to re-specify the task as needed. If effectors are not found to be suitable, new proposals can be sought by the helper through consultation with technology developers. These other stakeholders may be introduced to the OCN, as shown in Figure 5, after suitable discussions and precautions about privacy and security.

Step 4: Construction and Deployment

The final stage is the actual build and deployment of the smart-home solution. The sensors and effectors are dispatched to the home, and the same interface can be used to guide the care partner through their installation. The installation should be very simple, requiring only wireless sensors and effectors that can be easily attached to objects and to the home. Precise location of sensors and effectors should not be required. Sensors and effectors should automatically register with the previously installed smart-home hub computer, and then the HTN and ECM are set in motion.

DISCUSSION

This paper presented ASPIRE, an online collaborative network that connects stakeholders in the development of customized smart home solutions for aging-in-pace. One limitation of the work presented here is that it is in the prototype stage and lacks preliminary results to demonstrate the benefits of the ASPIRE platform. The next steps of ASPIRE development and implementation are to take the prototype described in this paper and evaluate its practicality and alignment with end users through a process of user-centered design. Focus groups, interviews and surveys will be used to evaluate the product, and will lead to refinements and to a final working prototype. Such a final prototype will be evaluated in the homes of older adults, providing further refinements and adaptations. We believe that the system thus designed will finally provide the portal that is needed for older adults and their care partners to design and build truly customized and effective smart homes.

A potential limitation of the concept is that older adult caregivers may be technology averse, and be unwilling to engage with the system as a whole. While older adults do tend to adopt novel technologies at a slower rate than other user groups, they are keen to engage with digital resources; as many as four in ten Americans over the age of 65% are smartphone users, for example, and 67% use the Internet [29]. Thorough user testing will be required to ensure acceptability and appropriate usability for the target demographic.

Further enhancements and improvements to ASPIRE are also being considered, including three dimensional maps and augmented reality for the specification of use cases (rather than the maps described above), integration of the platform with other stakeholders such as medical professionals care home staff, and further study of the control mechanisms.

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