Towards Intelligent Caring Agents for Aging-In-Place: Issues and Challenges

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Abstract—The aging of the world population presents vast societal and individual challenges. The relatively shrinking workforce to support the growing population of the elderly leads to a rapidly increasing amount of technological innovations in the field of elderly care. In this paper, we present an integrated framework consisting of various intelligent agents with their own specialties and responsibilities working in a holistic manner to assist, care, and accompany the elderly around the clock in the home environment. To support the independence of the elderly for Aging-In-Place (AIP), the intelligent agents must well understand the elderly, be fully aware of the home environment, possess high-level reasoning and learning capabilities, and provide appropriate tender care in the physical, cognitive, emotional, and social aspects. The intelligent agents sense in non-intrusive ways from different sources and provide wellness monitoring, recommendations, and services across diverse platforms and locations. They collaborate together and interact with the elderly in a natural and holistic manner to provide all-around tender care reactively and proactively. We present our implementation of the collaboration framework with a number of realized functionalities of the intelligent agents, highlighting its feasibility and importance in addressing various challenges in AIP.

I. INTRODUCTION

The world population is aging. The number of persons aged 60 or above is expected to increase from 841 million in 2013 to 2 billion in 2050 [1]. Furthermore, a survey [2] shows that nearly 90% of persons aged 65 or above indicate that they want to stay in their home as long as possible, among which four of five believe their current home is where they will always live. Thus, Aging-In-Place (AIP) or “the ability to live in one’s own home and community safely, independently, and comfortably, regardless of age, income, or ability level” [3] has received a significant amount of attention nowadays. However, there is still a huge gap between the demand for AIP and the available supporting equipment and technologies: Only 10% of the home improvement industry is dedicated to AIP [2]. Practical, affordable, and innovative technologies and equipment are proposed and implemented to narrow the gap.

Research on smart-home and ambient assisted living has been active in the past decade. However, most of the work focuses on providing fundamental services and upholding the physical or social well-being of the elderly. Because the capabilities of the elderly generally decline in all aspects (physical, cognitive, emotional, and social) as they age, they require all-around support in a holistic manner.

In this paper, we describe how the intelligent caring agents within a collaboration framework enable the elderly to maintain an active, healthy, and engaging life style in their own home by addressing the silver challenges in the aforementioned four aspects. Such an age-friendly intelligent system provides all-around tender care to the elderly including physical and cognitive assistance, constant companionship, social contact reminders, and recommendations in all aspects.

We design the intelligent agents to be heterogeneous that they have different specialties and capabilities. Each agent can work independently for the better well-being of the elderly in certain aspects. Nonetheless, they can work together in a coordinated fashion through the central controlling server. The collaboration framework is carefully designed to ensure the agents work seamlessly with each other and to resolve any inconsistency or conflict among them.

In the following sections, we present the major issues and some key technologies to address the corresponding challenges towards creating the intelligent caring agents for AIP. We then show the design principles of the collaboration framework and the intelligent agents exemplified with a number of realized functionalities. In the end, we conclude the paper.

II. ISSUES AND CHALLENGES FOR AGING-IN-PLACE

In this section, we present the major issues and challenges faced by the elderly for AIP as follows.

(1) Physical challenges: If the elderly choose to live independently in their home rather than nursing centres, then the major concern is how to ensure their physical safety. Typically, stationary (non-slippery floor) and mobile (wheelchair) physical support should be provided. However, relying on the others if accident happens is a more challenging task.

(2) Cognitive challenges: Due to the deterioration in cognitive abilities as they age, the elderly require both short-term (turning off the stove) and long-term (memory of past events) reminders. In addition, they need to pay more effort to pick up new skills and adapt to changes.

(3) Emotional challenges: The elderly tend to respond more to the positive stimuli than the negative ones [4]. Generally speaking, elderly require constant positive companionship to keep them away from loneliness, depression, and anxiety.

(4) Social challenges: Other than home, community is also included in the concept of AIP. It is important for the elderly
Intelligent agents should help the elderly in more ways, such as mobility [6] and to detect abnormalities [7]. However, most existing approaches have been applied to assist the elderly in determining when and how to provide assistance to the elderly.

Ambient intelligence, sensory inputs are seamlessly collected to resolve any inconsistency or conflict among them. The multiagent collaboration system is to define efficient and effective protocols for all agents to follow and at the same time resolve any inconsistency or conflict among them.

To get informed on the upcoming events that they may be interested in, to maintain socially active with existing contacts, and to acquire new friends.

(5) Other challenges: To ensure safety, the elder’s status should be all-around sensed in non-intrusive ways. Minimum surveillance should be used to protect privacy. Moreover, the devices required to convert one’s residence into an intelligent human-centered environment should be reliable and affordable.

III. KEY TECHNOLOGIES FOR AGING-IN-PLACE

In this section, we identify some key technologies and propose how these technologies should be advanced to better address the challenges faced by the elderly. The summary of the technologies and the corresponding challenges to be addressed is presented in Table I.

(1) Multiagent Collaboration: Technologies in multiagent systems [5] offer various types of coordination and cooperation framework for loosely-coupled autonomous entities or agents. The overall system can be considered as a collection of intelligent agents to meet the following requirements in AIP: (a) to perform unobtrusive sensing from multiple sources; (b) to guarantee ubiquitous access to information and assistance for all-around care; (c) to better serve the elderly with specialties; (d) to create more opportunities for interactions with the elderly. Other than collaborating with shared information or knowledge, the agents should also be able to work independently with partially available information or knowledge to ensure the elder is always taken care of by at least one agent due to possible system malfunctions. The big challenge in the multiagent collaboration system is to define efficient and feasible protocols for all agents to follow and at the same time resolve any inconsistency or conflict among them.

(2) Ambient assisted living: With the recent advance in ambient intelligence, sensory inputs are seamlessly collected to determine when and how to provide assistance to the elderly. Existing approaches have been applied to assist the elderly in mobility [6] and to detect abnormalities [7]. However, most assistance is provided to sense or support the elderly in the physical aspect. If adequate sensory inputs are integrated, the intelligent agents should help the elderly in more ways, such as monitoring the mental health of the elderly as well.

(3) Context awareness: Context awareness or behavior recognition enables the intelligent agents to be aware of the previous and current situations about the elderly and the home environment. Such information can be obtained from multiple sensory devices [8] or through a personal gadget such as a smartphone [9]. However, most context awareness technologies are limited to “when”, “who” [10], “where”, and “what”. Higher-level behavior recognition with richer context is desired, such as “how”, “with whom”, “happy or sad”, and “whether regular”. Having more appropriate and meaningful context awareness enables the agents to better understand the elderly and consequently provide more appropriate care.

(4) Persuasive technology: In information communication technology, persuasion is considered as a non-coercive way to change the attitudes or behaviors of the other party through negotiations [11]. In the case of human-agent interaction for AIP, the intelligent agents never initiate conversations for their own benefits (except for sustainability such as charging the battery of the smartphone) and they always persuade the elderly (reminder for prescribed medicine, encouragement for more physical exercise, suggestion for healthier dietary) without any form of enforcement. To perform persuasion through natural conversations [12], natural language processing, logical reasoning and inference, and natural language generation are the key building blocks of the intelligent agents. It is a big challenge to create agents with tender and caring personalities to dynamically deal with different elderly that have different personalities, behaviors, and needs.

(5) Individual modeling: The sensory inputs non-intrusively collected from the elderly and the home environment should be archived in a dedicated server together with the known information (personal preference and medical history). More importantly, high-level individual user profiles should be modeled based on all available knowledge. With individual modeling, the intelligent agents can serve more effectively [13] at appropriate time to avoid being annoying and provide better personalized applications [14] systematically with richer related context. However, autonomously mining the individual user pattern from historical data is never an easy task.

(6) Knowledge aggregation: There are two ways to aggregate knowledge within AIP. First, with the proliferation of crowdsourcing platforms, it is possible to elicit the help of the crowd to guide the elderly (instructions can be summarized by applying computational intelligence techniques [15]) to learn up-to-date knowledge and practice current technologies in more comprehensive manners. Therefore, instead of wasting time on traveling and waiting, the elderly may sit at home enjoying different online service through the intelligent agents, such as paying bills by internet banking, playing an online physical rehabilitation exercise game, or watching a video demonstration on how to prepare a healthy meal. The other

<table>
<thead>
<tr>
<th>Key technologies</th>
<th>Major challenges to be addressed</th>
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<tbody>
<tr>
<td>1. Multiagent collaboration</td>
<td>To ensure all-around care collaboratively and resolve inconsistencies and conflicts:</td>
</tr>
<tr>
<td></td>
<td>- physical (location, movement, health status); cognitive (when and where to provide reminders);</td>
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<tr>
<td></td>
<td>- emotional (provide maximal companionship).</td>
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<tr>
<td>2. Ambient assisted living</td>
<td>To assist the elderly with their physical or emotional (by sensing the mood) problems.</td>
</tr>
<tr>
<td>3. Context awareness</td>
<td>To provide richer contexts for physical, emotional, and social recognitions.</td>
</tr>
<tr>
<td>4. Persuasive technology</td>
<td>To improve the physical and emotional well-being of the elderly and keep them socially active.</td>
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<tr>
<td>5. Individual modeling</td>
<td>To personalize the provided services in AIP according to the individual differences:</td>
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<td></td>
<td>- physical (navigation and assistance at home); cognitive (reminder and skill set);</td>
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<tr>
<td></td>
<td>- emotional (mental illness history); and social (spiritual group and acquaintances).</td>
</tr>
<tr>
<td>6. Knowledge aggregation</td>
<td>To summarize cognitive knowledge and obtain common characteristics within groups.</td>
</tr>
<tr>
<td>7. Emotion recognition</td>
<td>To provide constant positive companionship and prevent emotional problems.</td>
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TABLE I. THE KEY TECHNOLOGIES TO ADDRESS THE CHALLENGES FOR AIP
way of knowledge aggregation for AIP is more towards big data analysis on user patterns. If anonymous user data is collected and analyzed, the results are helpful to recognize different behavioral patterns among the elderly and consequently provide more related service to each individual (similar to give merchandise recommendations during online shopping [16]).

(7) Emotion recognition: Many existing work focuses on the personification of the virtual agent through human-agent interactions [17]. Only a few focus on the mood awareness of the human [18] (besides emotion recognition through facial expressions and speech signals). The major challenge in emotion recognition is how to collect adequate reliable sensory inputs in non-intrusive ways to assess the user emotion. However, to provide effective emotional support and to deliver human-like virtual companionship, mood awareness of the elderly is a necessary module for the intelligent caring agents.

IV. DESIGN PRINCIPLES

In this section, we present the design principles of the intelligent caring agents for AIP within a collaboration framework. Fig. 1 illustrates a multiaagent system consisting of three agents: a smart butler residing in the smartphone, a virtual nurse residing in the computer, and a robotic dog with mobility. The assumptions taken are: (a) the elder always carries the smartphone (butler application activated) on the waist belt with a holder (replaceable with a set of unobtrusive wearable sensors with real-time wireless communication capabilities); (b) the virtual nurse is activated during day-time and could appear on one of the display panels (computer monitor, TV, and any other mobile or stationary screens) at any time; (c) the robotic dog, which is able to move freely on the floor and provides visual inputs, is activated upon commands (from the elder or agents) to reduce unnecessary energy consumption.

Based on the application framework illustrated in Fig. 1, we identify the major design principles as follows. The summary of mapping the design principles to the afore-reviewed corresponding key technologies is given in Table II.

(1) Each agent has a unique set of knowledge and expertise to support the elder in different aspects. For example, the butler takes care of the activity plans of the elder and is responsible for generating reminders (with dynamically changing priorities); the nurse is an expert in health care and is responsible for providing health related advices (type of rehabilitation exercise); the robot dog provides actual companionship (touch and attract attention) and gathers visual inputs for activity recognition, if permitted. All three agents collaborate together to sort out the agreed priorities of different individual tasks to avoid confusions or talking to the elder at the same time and resolve conflicts in activity recognition based on the individual specialties and the reliabilities of the sensory inputs.

<table>
<thead>
<tr>
<th>Design principles</th>
<th>Corresponding key technologies</th>
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<tbody>
<tr>
<td>1. Diverse domain knowledge</td>
<td>Multiagent collaboration, ambient assisted living, individual modeling, knowledge aggregation, and emotion recognition</td>
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<tr>
<td>2. Independent functionalities</td>
<td>Multiagent collaboration and context awareness</td>
</tr>
<tr>
<td>3. Natural interactions</td>
<td>Persuasive technology, individual modeling, and emotion recognition</td>
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<tr>
<td>4. Special requirements</td>
<td>Ambient assisted living and individual modeling</td>
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<tr>
<td>5. Maintain socially active</td>
<td>Context awareness, persuasive technology, and individual modelling</td>
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</table>
(2) Each agent is able to work independently to support the elder but at the same time plays its part contributing to the overall goal of all-around sensing and care. For example, when the elder goes out, the butler residing in the smartphone is relied on. When the elder goes to the bathroom without bringing the smartphone, the robot dog can move over to check the status of the elder.

(3) The interactions between the elder and the agents should be as natural as possible. For example, reminders and recommendations can be conveyed to the elder through small talks in natural language. Although full understanding and generation of the natural conversations remain as big challenges, the system can use certain existing technologies for natural language processing, parsing, and generation.

(4) Special needs of the elder can be identified and catered by different agents. For example, if the elder suffers from dementia, the priorities of reminders should be increased by the butler, who should also attract more attention (vibration and sound); if the elder requires intensive health monitoring, the nurse should be more active and may require additional wearable sensors (to measure heart rate and blood pressure in real-time) and physically installed ones (to detect fall down or other critical conditions); if the elder suffers from certain physical incapability such as poor eye sights, the robot dog plays a more important role to assist in navigation and should proactively clear hazardous obstacles along the path ways.

(5) Agents must help the elder to maintain an active social life. With the internet connectivity of the butler and the nurse, the elder could easily remain active on social network service platforms. If the elder has not been responsive to friends’ updates or has not logged into one’s own account recently, persuasive conversations are initiated. Furthermore, if evidence shows the elder has any abnormal conditions (both mentally and physically), family members, neighborhood watchers, or other concerned parties (nearest hospital, police station, or caring service providers) should be notified through text messages, email alerts, or direct calls.

V. SYSTEM IMPLEMENTATION

Although the realization of the overall system is still ongoing, we present the implemented modules of the butler, the nurse, and the collaboration framework in this section.

A. Implementation platforms

Due to the distributed nature of the multiagent system and the diversity of the challenges to be addressed, different agents or work require different developing tools and programming languages in different platforms. The butler is implemented in Java and XML as an Android application for smartphones and tablets. The nurse is implemented in C# using the Unity 3-D engine as a computer program. The collaboration proxy is implemented using the NodeJS framework (server-side JavaScript platform).

B. Discussion on feasibility and practicability

There is a common stereotype that the elderly are not receptive to advanced technological gadgets. However, Czaja [19] shows that although less confident that younger people, elderly who have experiences of using the modern gadgets generally hold more positive attitudes and greater confidence. If computers (extensible to smartphones) are modified according to the specific needs of the elderly with simpler interfaces that follow the natural mental concepts, the elderly can benefit much from them [19]. Moreover, the usage of internet, computers, and social network service platforms among the elderly keeps increasing over the past decade [20]. Therefore, deploying the agents in the smartphone and computer is a feasible and practical way to assist the daily lives of the elderly.

In addition, our proposed collaboration framework consisting of intelligent agents does not involve much financial costs. Because the current smartphone penetration rate in many developing and developed countries is high [21], many elderly can use the smartphones that they already have. Moreover, as discussed earlier that each agent in the collaboration framework can work independently, excluding the expensive robot dog does not make the overall framework obsolete.

C. Overall system architecture

The overall system architecture is presented in Fig. 2. The central controlling server (Home-care Knowledge Server) consists of the following components: (1) the collaboration proxy, which ensures the cooperation among the agents and resolves any inconsistency or conflict (elaborated in Section V-F), (2) the situation model, where both the dynamic situation of the elder as well as the environment (the elder is now in the living-room) and the static information (the living room is next to the master bedroom) are stored, (3) the recognized activity patterns of the elder (normally wakes up at 6:30 am in the morning during weekdays), (4) the ontology database, where the relationship properties are stored, (5) the entity database, where the details of the subjects are stored, (6) the history log, where all the past information are archived, (7) the service interface, which flexibly connects the agents to the overall system. Other than the smart butler (elaborated in Section V-D) and the virtual nurse (elaborated in Section V-E), sensors can also be considered as (non-intelligent) agents. It would be interesting to enable frequent interactions between the virtual agents and the Home-care Social Network, which consists of the concerned parties of the elder such as the relatives, friends, care-takes, and people from nearby police station and hospital.

In this way, the intelligent agents would be more human-like and the concerned parties can constantly query the status of the elder through the agents to avoid unnecessary interrupts.

D. Smart butler

The graphical user interface of the smart butler is shown in Fig. 3(a). The background picture shows the elder is currently in the living room. The context panel on top shows (1) the real-time weather and the temperature reading taken from the official website; (2) the current time and the date; (3) the emoticon that reflects the affective state of the elder. The emoticon button allows the elder to explicitly annotate his or her affective state. When pressed, a drop-down list is displayed (see Figure 3(b)) for the elder to annotate one of the nine affective states. All the chosen affective states follow the well-known circumplex model of affect [22]. A computational activity-affect model [23] has been introduced to predict the elder’s affective state (based on the recognized activities that the
elder performed or experienced), which will be automatically updated in the interface. The computational model (in neural network form) imports the initial domain knowledge from the published work in psychology and gerontology and takes the mood annotations and keyword detections as the training signals. After adequate training, how the recognized activity affect the mood of the individual elder can be successfully modeled. By utilizing the individual activity-affect model for mood awareness of the elder, more specific and appropriate tender care can be provided (more details are available in [23]). Fig. 3(c) shows a simple example alert message that our implemented smart butler sends to the daughter of the elder.

The function panel of the smart butler shown in the middle of Fig. 3(a) consists of six major functionalities provided to the elder: (1) “Play” streams the video clips (online) for physical exercise (Yoga, dance, and Tai-chi) and offers various mental exercising games (online) as cognitive stimuli [24]. (2) “Social” allows the elder to call, message, or interact (through social network service platforms) with others. (3) “Learn” helps the elder to acquire new or review mastered skill sets either locally (video clips recorded by family members) or online (step-by-step instructions from crowdsourcing platforms). (4) “AboutMe” keeps the personal profile and the contacts of the concerned parties. (5) “Calendar” stores the personal schedule of the elder, upon which reminders with dynamically changing priorities will be delivered at the corresponding time. (6) “Memory” stores or retrieves the episodic memory of the elder with the associated (annotated or estimated) affective states in multimedia (pictures and music) formats. We try to integrate all the applications that the elderly normally use (call, message, internet surfing, and online social networking) and our implemented ones into the sub-functions of the smart butler. Therefore, the elderly would only need to interact with
the smart butler for all kinds of usages of the smartphone.

The interact panel of the smart butler shown in the bottom of Figure 3(a) illustrates how the smart butler interacts (currently in text) with the elder. In the interact panel, the smart butler always initiates the interactions. On the other hand, in the function panel, the elder decides which particular type of service is needed. However, through the interact panel, the elder can also be directed to one of the functions listed in the function panel. When necessary, a pop-up frame with more detailed or more critical information can be shown to the elder. Moreover, within the interaction frames, text and choice input boxes are provided for the elder to provide responses.

The current prioritized recommendation system implemented in the smart butler is hard-coded. For example:

(1) A low-level reminder will be generated five minutes before the scheduled time for the elder to take the prescribed medicine: “Master, it is about time to take your medicine!” Messages of this priority can be ignored and will disappear from the screen after a short while (time varies for different type of reminders).

(2) A medium-level reminder will be generated five minutes after the scheduled time to take medicine: “Have you taken your medicine already?” Messages of this priority are delivered with vibration and alarm to attract more attention. Moreover, the messages will remain on the screen until the elder responses (through the “Yes” or “No” buttons provided).

(3) A high-level reminder will be generated if the smart butler has not received any response from the elder (time varies for different type of reminders): “Seems you still have not taken your medicine and I have sent a SMS to your daughter...” Messages of this priority initiate communication with other agents or the concerned parties. Moreover, the screen of the smartphone will be locked until the elder responses.

E. Virtual nurse

The virtual nurse (see Fig. 4) is an agent based character specializing in health care, whose 3-D high-resolution avatar is displayed on the 2-D large screen. This design enables the virtual nurse to show more expressions (facial expressions, body postures, and hand gestures) during the natural conversations with the elderly for conveying its emotional response. Other than health related support, the virtual nurse provides a wide range of care-giving functions in a holistic manner: (1) querying the well-being of the elder, (2) giving gentle medication reminders, (3) encouraging healthier living style, such as proper physical and mental exercises, healthier dietary, life-long learning, and social engagement with the others, (4) providing suggestions for stress reduction. Some of the functions are shared with the virtual butler.

To make the virtual nurse not only look realistic but also have natural and human-like behaviors, the following three key characteristics of modeling realistic agents [25] are considered: (1) autonomy: agents can function on their own, (2) interactivity: agents can interact naturally with other agents, human players, and the environment, (3) personality: agents can exhibit human traits and characteristics. Working towards these challenges, we propose a brain-inspired agent architecture (using the fusion ART [26] neural network for knowledge storage, retrieval, and adaptation) that integrates autonomy, natural language interaction, and human-like personality. The system architecture of the virtual nurse is presented in Fig. 5. The intention or response of the elder is interpreted from the input (either text or speech) by the Speech Recognition and Natural Language Understanding (NLU) module. After processing the information, the virtual nurse answers or responses to the elder (both text and speech) through the Dialogue Management and Natural Language Generation (NLG) module and animates its facial expression, body posture, and hand gesture through the Non-Verbal Behavior module. The speech-to-text and text-to-speech functions are realized by integrating the MicroSoft Speech Recognition tool.

Unlike the smart butler (using the embedded sensors of the smartphone), the virtual nurse can only query the situation of the elder from other agents or sensors (besides through natural conversations). In this case, the virtual nurse replies on the collaboration proxy to acquire such information.

F. Collaboration proxy with simulations

The overall system implemented for AIP consists of intelligent caring agents that each serves the elderly in a holistic manner. Besides maintaining the accurate perception or beliefs about the situation of the elderly and reactively producing relevant or meaningful response, all agents have
social (communication) capabilities ranging from proactively recommending the appropriate options for food or exercise to persuading the elderly to change their decisions. This implies that the system needs to maintain commitments and represent the respective beliefs, wants, and intentions [27]. For example, when an agent generates an important reminder for taking the prescribed medicine, the system needs to ensure that the elder performs the reminded action (by answering the specific question), before allowing all agents to interact with the elder for other tasks with lower priority.

An agent by itself is a fully functional application which can be deployed dynamically in multiple platforms. The agents can communicate with each other to exchange information, coordinate their activities, and adapt their roles within the multiagent system [28]. As discussed earlier, the agents are heterogeneous and can work independently to serve the elderly in a holistic manner. However, they must be able to work together in a coordinated fashion when coexist.

We develop each intelligent agent based on the standard framework in which there is an interface that flexibly connects the agents to the overall system. Because each agent may need to process the mental abstraction of the elder, we use a nested structure of the mental attributes of the elder as the main knowledge representation to be exchanged between the agents to support the coordination and collaboration [29], [30]. The standard protocol supporting the representation of different aspects is presented as follows: (1) mental modalities of belief, desire, intention, and capability, (2) Individual and group mental attributes, (3) Temporal modalities of the present, near future, and persistent event for all mental attributes, (4) Possibility of a future event and the intentional states.

We have developed a simulation environment (see Fig. 6) to test the framework and explore different coordination and collaboration situations. The simulation environment is a virtual home in which the elder avatar performs certain daily-tasks (controlled manually or by generated routine). In the simulation environment, we can show different types of interdependency among the agents as follows:

(1) **Inconsistency**: Two or more agents have contradictory beliefs. For example: agent $i$ says the elder is unconscious but agent $j$ says fully awake (see Fig. 7).

(2) **Conflict**: Two or more agents have different goals that may cancel out each other. For example: agent $i$ intends to suggest the elder to take a nap after taking the prescribed medicine but agent $j$ recommends to play games.

(3) **Cooperation**: Any agent can help the others. For example: agent $i$ wants to but cannot know the elder’s current location, then agent $i$ queries the location from agent $j$.

(4) **Support**: When one agent makes certain suggestion, another agent generates a supporting recommendation. For example: agent $i$ suggests the elder for healthier dietary and agent $j$ supports agent $i$ by stating that the elder has not eaten that for a long time (see Fig. 8).

We implement a collaboration proxy to continuously collect the standardized information update from all the intelligent agents, detect any belief inconsistency, possible conflict, or potential for cooperation, and send information to the concerned agents to resolve the situation (if required). In other words, the proxy manages the collaboration among all the agents by ensuring the consistency of their aggregated mental states. The pseudo code for the coordination proxy is given as follows [31]:

```plaintext
1 WHILE True
2   Receive message $Msg_a$ from agent $a$
3   IF $Msg_a$ is an assertion
4     Compare $Msg_a$ with all other assertions in $M$
5     IF $Msg_a$ is a belief and inconsistent with $Msg_b' \in M$
6       Notify $a$ and $b$ about inconsistency
7     IF $Msg_a$ is a goal and conflicting with $Msg_b' \in M$
8       Notify $a$ and $b$ about the conflict
9     IF $Msg_a$ is a desire and $a$ is incapable to achieve it
10    IF from $M$, there is agent $b$ capable to achieve it
11       Notify $b$ to help $a$ for $Msg_a$
12   Update $M$ based on $Msg_a$
```

VI. Conclusion

In this paper, we outline the issues and challenges in the emerging application domain of aging-in-place and how they can be addressed by advancing and applying the identified key technologies. More importantly, we present a collaboration framework consisting of intelligent caring agents with different
specialties to provide all-around tender care to the elderly. Although the overall framework is designed for the elderly who generally require frequent attention, constant companionship, and deep understanding, it can be easily altered for similar contexts (patients who require special treatments at home) or adapted generally for monitoring the well-being of everyone in all the physical, cognitive, emotional, and social aspects. We have already implemented a number of functionalities of the intelligent agents and the collaboration framework and we are currently working towards realizing all the rest proposed functionalities. In summary, we do believe the advances in aging-in-place will greatly benefit from the cutting-edge research contributed by the computational intelligence community.

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REFERENCES
