REALIZATION OF AGEING-FRIENDLY SMART HOME SYSTEM WITH COMPUTATIONAL INTELLIGENCE

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To tackle a number of challenging difficulties in the coming aged society, we consider intelligent design of the residential space as a solution approach to realize "independence, social connectivity and maintained productivity" for older persons. We first review the contemporary technologies involved in constructing smart homes world-wide and then report our experiences of implementing a smart home with various automation subsystems along with robotic agents and health monitoring subsystem. For reduction of human intervention during home operation, long-term learning of human behavior is studied for continued service by robotic systems, for which a couple of computational intelligence-based algorithms are utilized. Then, we discuss some important issues on smart home systems for older persons including technical direction, role of computational intelligence techniques and design philosophy.

1. Introduction

Shortage of caregivers is recognized as a world-wide problem. It has been reported that the old-age dependency ratio (number of people 65 or older over number of people ages 20-64 [1]) will be doubled within the next three decades. This will cause considerable lack of caregivers and living spaces for the elderly.

The problematic portion in a population pyramid, rendered due to high percentage of the elderly, can possibly be resolved by a careful design of a residential space (e.g., a smart home) in a way that independence, social connectivity and maintained productivity are successfully brought to the users. There are a number of complex issues, however, as indicated in [2]. We thus propose to include robotic agents and health-monitoring components as equally important constituents of the futuristic smart home system in consideration of

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concerns and limitations of a current smart-home technology on system automation. In addition, for human-friendly interaction between the human user and the smart home system, we suggest that the agents in a smart home system are required to have some important cognitive functions and expressive functions in terms of various techniques of computational intelligence.

The paper is organized as follows. We first review in Section 2 those well-known contemporary technologies involved in realizing smart home systems world-wide; subsequently, we report our experiences of implementing a smart home with various automation subsystems along with robotic agents and health monitoring subsystem. In Section 3, we assert that reduction of human intervention and long-term learning are particularly important and that computational intelligence can play a central role to achieve those goals. We make concluding remarks in Section 4 with brief discussion on technical direction, an extended role of computational intelligence techniques for human-robot interaction environment and our design philosophy.

2. Smart Homes World-Wide

There have been various types of smart homes world-wide. For example, ubiHome (see [3],[4]) at GIST, Korea, provides context-based automated services, a tangible user interface, and a virtual reality-based augmented environment. In TRON intelligent house at University of Tokyo, Japan, a computer-aided system has been built in collaboration with 15 companies [5]. It seems that the contents of services in ubiHome and TRON are much the same as in Millennium Homes at University of Brunel, UK [6] or in the Intelligent Dormitory 2: iSpace2 at University of Essex, UK [7]. However, ubiHome, TRON, and Millennium Homes bear little resemblance to iSpace2, in the sense that an ambiguity issue has been addressed. In the smart SoftWareHouse at University of Zurich, Swiss, this issue has been carefully resolved by introducing machine learning and data mining techniques which offer various functions, such as activity monitoring, knowledge discovery, relational knowledge learning [8]. It can be seen that, for a human-friendly interaction between the user and the home system, some important cognitive functions and corresponding learning functions are realized in terms of various techniques of computational intelligence.

2.1. *Smart Home System with Robotic Agents*

Robotic agents have been considered as a useful means of human-friendly interaction [9] due to the fact that their maneuvering capability enables the system to provide physical services and that their human-like appearance enables it to provide emotional services. The Intelligent Sweet Home (ISH, see Fig. 1) at KAIST, Korea, exemplifies how the quality of services can be improved by assistive robotic agents [9,10]. The robotic agent group includes a steward robot that serves as a coordinator, an intelligent wheelchair capable of automatic maneuver and obstacle avoidance, a robotic sling agent that fetches and lifts the user, an intelligent bed that can automatically push/pull its table and performs posture estimation (Fig. 2). All the agents co-operate over a pre-defined communication protocol, which is mediated by a server system. Note that there is another agent, called Softremocon system, which recognizes various hand gestures (see Fig. 3).

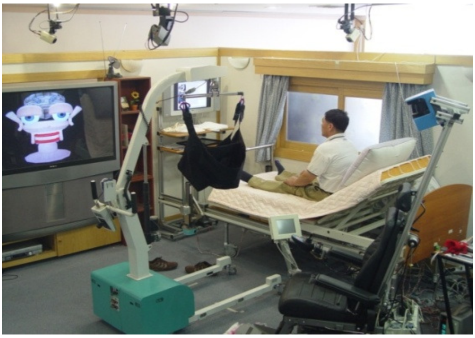

Figure 1. Intelligent Sweet Home (ISH) system at KAIST, Korea.

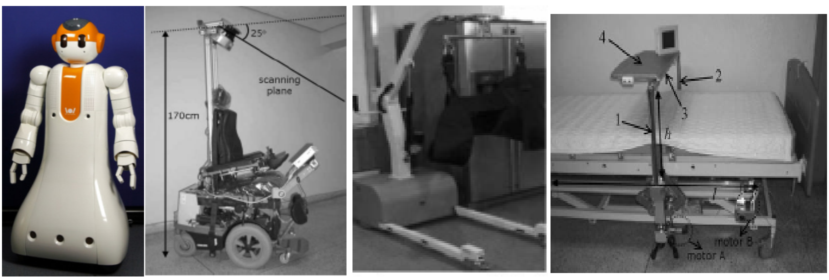

Figure 2. Various robotic agents in ISH [9]. (From the left: Steward robot, intelligent wheelchair, robotic sling agent, intelligent bed)

2.2. *Smart Home System with Health Monitoring System*

Health monitoring technologies for a smart home system have emerged and integrated to meet the needs of the elderly and the disabled. First, an early-stage of development includes integrated systems with existing technologies. Smartest

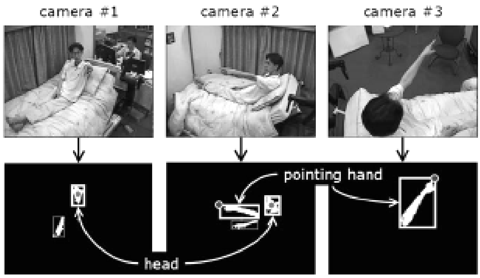

Figure 3. 3D Hand gesture recognition system in ISH [9].

Home at Smart Home Center, Netherlands [11], has managed twenty smart homes which were build for a healthcare study for the elderly; they provide with a multitude of functions such as activity monitoring, automatic lightning, and telemedicine, etc. A research team at University of Coruna, Spain, has suggested a new paradigm "Telegerontology" [12] where internet-based rehabilitation services and telemedicine techniques are integrated. Inhaus-Zentrum at Fraunhofer-inHaus-Center [13], Germany, provides with smart home facilities for the elderly such as a smart gate and a smart bathroom; the system "inBath-Assistive Bathroom Surroundings" has been demonstrated in Cebit exhibition.

Recognition functions have been integrated for personal health care systems. In a Smart Medical Home [14] at University of Rochester, USA, a virtual agent "Chester" provides medical advises; "Inspector" examines skin troubles based on a vision-based recognition technologies; "Memory assistance" indicates the location of home appliances.

There is an emerging trend towards development of a global consortium within the smart home research community. In an EU-wide project, NUADU, research groups in 5 countries and 21 partners have developed various smart home technologies to help the elderly to remember their daily schedule and maintain social contact. A similar line of research project, COGKNOW [15], which includes research groups in 6 countries and 11 partners have extensively investigated problems of people with mild dementia and have developed various remedies from a technical point of view (e.g., see Fig. 5).

3. Computational Intelligence Issues for Realization of a Futuristic Smart Home System

It can be seen from the smart home studies mentioned earlier, computational intelligence is strongly pertinent to development of various types of smart home systems for the elderly and the disabled. We note in this section that reduction of

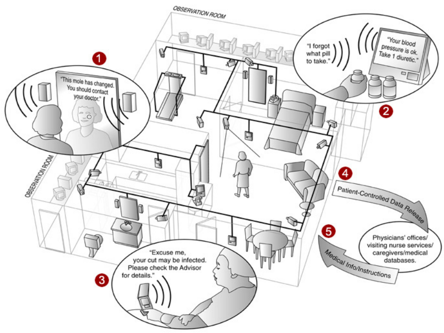

Figure 4 [14] (left). Smart Medical Home at University of Rochester, USA.

Figure 5 [15] (right). A smart schedule reminder developed in COGKNOW project.

human intervention and long-term learning are particularly important and that computational intelligence has a central role to achieve those goals.

The Intelligent Sweet Home (ISH, Fig. 1) at KAIST, Korea, has been designed in a way that the quality of services can be improved by assistive robotic agents for which a set of computational intelligence modules conduct various intelligent functions including operations on cognition and decision making. From our decade-long experiences with the smart home system, we have observed that, in order for the computational intelligence techniques to be useful for the disabled and the elderly in a smart home system, two issues on learning needs to be carefully addressed and resolved: learning over a variety of time scales and learning without intervention. Learning on those conditions is becoming more important mainly because those users have a limited physical capability. To resolve this issue, we have suggested a life-long learning framework [16] and a non-supervised learning framework [17].

The key idea in the life-long learning is to provide a good blend of an inductive learning process and a deductive learning process; in the inductive learning process, the parameters of the underlying knowledge bases (called "Probabilistic Fuzzy Rule Base" and "Context Description Set" [16]), and in the deductive learning process, some of the knowledge bases are ruled out or grafted according to environmental changes. In particular, the knowledge bases are processed throughout both a short-term memory and a long-term memory, whose chain process is much similar to the one in a human brain. The computational intelligence meets the human intelligence indeed.

The non-supervised learning framework [17] provides with a technical base by which a sequence of a human action can be learned optimally in the sense of class-separability. What makes this framework have a definite edge over other kinds of learning methods is its plausible assumption that a human action and decision making can not only be made based on one's knowledge (or preference), but also be affected or hampered by changes in environment. Hence, the pattern learning in the suggested framework unfolds an interaction between a human knowledge and a situation in an external world.

4. Concluding Remarks

We have shown that the smart home realization is a world-wide issue and that integration of robotic agents and health monitoring systems are essential in implementing a smart home for the aged. Since those users have a limited access to such functions, it has been suggested that reduction of human intervention and automated long-term learning are particularly important and that computational intelligence can play a central role to achieve those goals. Therefore, the future smart home environment for the elderly should be able to understand user's mind and adapt to an environment that constantly changes, which would require proper use of various computational intelligence techniques.

Equally important is provision of proper facility in the home environment to promote productive activities so as to maintain social contacts and have personal pride. When designing an ageing-friendly smart home system with computational intelligence, one should carefully handle the human issue as much as the social issue so that independence, social connectivity and maintained productivity are successfully brought to the users.

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