Title
Toward Healthy and Successful Aging: Intelligent Home Care Environments for the Elderly

Author
Chiu, Hsin-Hsien

Publication Date
2013

Peer reviewed|Thesis/dissertation

Toward Healthy and Successful Aging:

Intelligent Home Care Environments for the Elderly

by

Hsin-Hsien Chiu

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

In

Architecture

and the Designated Emphasis

in

New Media

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Yehuda E. Kalay, Chair

Professor Galen Cranz

Professor William A. Satariano

Professor Kimiko Ryokai

Fall 2013

Toward Healthy and Successful Aging:

Intelligent Home Care Environments for the Elderly

Abstract

Toward Healthy and Successful Aging:

Intelligent Home Care Environments for the Elderly

by

Hsin-Hsien Chiu

Doctor of Philosophy in Architecture

Designated Emphasis in New Media

University of California, Berkeley

Professor Yehuda Kalay, Chair

Due to increases in chronic diseases, hospital costs, and aging populations, home care has become a growing worldwide trend in elder care. This research proposes Intelligent Home Care Environment (IHCE) as a solution that can assist the elderly with physical and cognitive functioning, while reducing costs and avoiding the social and cultural problems associated with current solutions.

In order to research the interrelationship between the elderly and their physical environments in home care, this study starts with ecological models (Satariano, 2006) of human-environment relationships and the disablement model (Verbrugge & Jette, 1994) that is used in the epidemiology of aging and gerontology. Then, Acupuncture Theory (Ming-Tung Chen, 2000; Zhang & Rose, 2001) is employed as a metaphor/model for formulating a Dynamic Multi-Agent System (DMAS) that can dynamically respond to ever-changing events in the environment; this is a way to design the physical environment as a "living ecology". Finally, to consider how the elderly are assisted in home care from a social and cultural perspective, quantitative and qualitative case studies describe how personal and cultural tastes affect the user's physical and cognitive functioning. The Healthy Aging Network Study provides the representative samples for system testing and evaluation.

The objectives of the IHCE are to assist the elderly through the optimization of safety, adaptability, and resource efficiency. From the viewpoint of gerontology, successful aging requires three attributes: 1) Low risk of disease and disease-related disability, 2) High mental and physical function, and 3) Active engagement with life (especially socially engaged) (Rowe & Kahn, 1997). With the assistance of IHCE, the elderly may live more independently, have higher self-confidence, and enjoy successful, well-balanced, and healthy aging.

Acknowledgements

I would like to especially thank the following professors for their precious assistance to my dissertation:

Professor Yehuda E. Kalay (Architecture, Dissertation Chair)
Professor Galen Cranz (Architecture, Ph.D. Qualifying Exam Chair)
Professor William A.Satariano (School of Public Health)
Professor Kimiko Ryokai (School of Information)
Professor Andrew Shanken (Architecture)

I sincerely appreciate all your invaluable help, advice, and encouragements to both my research and life at Berkeley. Meanwhile, I would like to thank Prof. Nezar AlSayyad and Prof. Gail Brager from Dept. of Architecture, and Prof. David Bates, Prof. Ken Goldberg, Prof. Abigail De Kosnik from Berkeley Center for New Media, for hosting wonderful lectures/ events with intellectual discourses that nourish my research, including fellowship awards as financial support. Finally, I must thank all the members of Digital Design Research Group and Berkeley Center for New Media for your warm camaraderie as my extended family at Cal.

I would like to dedicate this dissertation to:

My parents: Jia-Juh Chiu, Yuh-Chai Tsay

and family: Hsin-Hung Chiu

for their endless support,

The Principle of Chinese Qi and Healing Association:

Master Ming-Tung Chen

for his precious inspiration as my life mentor.

Table of Contents

Abstract…… 1
Acknowledgements…… i
Table of Contents…… iii
List of Figures…… vii
List of Tables…… ix

Chapter I Introduction to Research Issues 1
1.1 Issues in Physical Environments 1
1.2 Issues in Home Care 2
1.3 Research Questions 4

PART I Literature Review 5

Chapter II Design Intelligent Environments as Living Ecology 5
2.1 Intelligent Environments 5
2.1.1 Idea of Intelligent Environments 5
2.1.2 Current Approaches 6
2.1.3 Comparisons and Critiques of Current Approaches 7
2.2 Rationale of Intelligent Environments 10
2.3 Interaction between the Environment and the Occupant 10
2.3.1 What Is an Agent? 10
2.3.2 When Can an Agent Be Considered "Intelligent?" 11
2.4 Fundamental Composition of Intelligent Environments 12
2.5 Agent-Based Intelligent Environments 12
2.5.1 Single Agent-Based Intelligent Environments 12
2.5.2 Multi Agent- Based Intelligent Environments 14
2.6 Design an Intelligent Environment as a Living System 15
2.6.1 The Environment as Context 15
2.6.2 The Environment as a Machine 16

2.6.3 The Environment as Living Ecology 16
2.7 Conclusion 16

Chapter III Home Care Environments 17
3.1 Issues of Aging 17
3.1.1 Epidemiology of Aging 17
3.1.2 An Ecological Model of Aging 17
3.1.3 The Disablement Model 19
3.2 Why People Choose Home Care 19
3.3 Comparisons among Different Medical Organizations 20
3.4 Current Approaches 23
3.4.1 Barrier-Free Design/ Universal Design 23
3.4.2 Patient-centered Assistant Technologies 24
3.4.3 Monitoring System: E-Health 24
3.5 Conclusion 25

PART II Developing Research Methods 26

Chapter IV Hypotheses and Research Methods 26
4.1 Research Hypotheses 26
4.2 Research Methods 27
4.2.1 The On-Site Case Study in Home Care 28
4.2.2 System Development of Intelligent Home Care Environments 29
4.2.3 System Testing and Evaluation for External Validity 30
4.3 Conclusion 32

Chapter V Developing User Profiles for Intelligent Home Care Environments and Identifying Representative Types of Health Issues 34
5.1 On-site Case Study 34
5.1.1 Data Collection 35
5.1.2 Photo Analyses 38
5.1.3 Finding 39
5.1.4 The Home Care Service Profile 42
5.1.5 The Personal Taste Profile 43

5.2 Cross-Cultural and Ethical Variation Studies in Home Care 44
5.2.1 Cross-Cultural and Ethical Variation Comparison 44
5.2.2 Cultural Evaluation Form 45
5.3 Healthy Aging Network Walking Study (HANS)... 47
5.3.1 Sample Background 47
5.3.2 Interview Instrument of Healthy Aging Network Walking Study (HANS) 47
5.3.3 Statistical Data Analyses for Developing Representative Samples........................ 50
5.4 Conclusion.. 54

PART III System Development and Testing 58

Chapter VI System Development of Intelligent Home Care Environments............................. 58
6.1 Applying Acupuncture Theory as a Metaphor/ Model 58
6.1.1 The Manifestation of Yin and Yang from the Macrocosm to the Microcosm........ 59
6.1.2 Acupuncture Points and Twelve Channels and Collaterals 59
6.1.3 Five Phases and Correspondences in Acupuncture 61
6.1.4 A Holistic Intelligent Multi- Agent Intelligent Environment 62
6.2 Dynamic Multi-Agent System Development (DMAS)... 62
6.2.1 Multiple Subsystems and the Dynamic Hierarchy... 62
6.2.2 Dynamic Grouping and Control Scope.. 63
6.2.3 System Structure and Optimization between Safety, Resource Efficiency, and Adaptability 64
6.3 Formulating Physical Environments of IHCE.. 67
6.3.1 Space Composition 67
6.3.2 Theories of Human-Environmental Interaction 67
6.3.3 Interface Design of Intelligent Home Care Environments 76
6.4 Conclusion.. 80

Chapter VII System Testing and Evaluation Using Scenarios.. 81
7.1 Reactive/ Proactive assistance in Activities of Daily Living (ADL)/ Instrumental Activities of Daily Living (IADL) 84
7.2 Safety Issues (Code Blue) 100
7.2.1 Fall Monitoring 100
7.2.2 Suspicious Events Monitoring 105

7.3 Multiple Activity Scenario Evaluation ... 108
7.4 System Testing and Evaluation with Scenarios ... 116
7.4.1 Scenario 01: Dressing/ Bathing/ Laundry ... 117
7.4.2 Scenario 02: Meal Preparation ... 121
7.4.3 Scenario 03: Fall Monitoring ... 124
7.4.4 Scenario 04: Suspicious Events Monitoring ... 126
7.4.5 Scenario 05: Multiple Activity Scenario ... 129
7.5 Conclusion ... 137

PART IV ... 138

Chapter VIII Conclusions ... 138
8.1 Research Strength ... 138
8.2 Potential Applications & Research Outcomes ... 140
8.3 Future Directions ... 140

Bibliography ... 141

List of Figures

Fig. 1 The diagram explains the idea of the environment and users being in balance. 2
Fig. 2 Interaction between the environment and an agent 10
Fig. 3 Interaction between an intelligent agent and the environment 11
Fig. 4 The fundamental composition of intelligent environments 12
Fig. 5 The composition of centralized intelligent agent system 13
Fig. 6 On the left, the composition of the assistive heal care robot. On the right, the assistive robot helps the user to open a door with the handle tighten with a colored towel. 14
Fig. 7 The composition of a distributed intelligent agents system 15
Fig. 8 The Ecological Model (from U.S. Department of Health and Human Services) 17
Fig. 9 The Ecological Model in epidemiology of aging (Satariano, 2006) 18
Fig. 10 The Disablement Model (Verburgge & Jette, 1994; Guralnik & Ferrucci, 2003) 19
Fig. 11 Interior of a patient room at Virginia Hospital Center , VA, USA (Virginia Hospital Center, 2013)... 21
Fig. 12 The interior of the living room in a nursing home (Karen Hanson, 2012) 21
Fig. 13 The interior of the bedroom in home care (Mossaic Home Care Services, 2013) 22
Fig. 14 The diagram of Intelligent Home Care Environment (IHCE) 30
Fig. 15 Taste Analysis of the Interior- Caretaker 01 38
Fig. 16 Comparison of Home Care Service Quality between caretakers 01-04 39
Fig. 17 Home Care Service Quality (Patient’s Level of Satisfaction) 40
Fig. 18 Supportability of The Patient’s Taste (Based on the Patients’ Satisfaction) 41
Fig. 19 The concept of energy flow between human body and the environment through human skin 59
Fig. 20 The illustration of acupuncture points (Ming-Tung Chen, 2000). 60
Fig. 21 The five phases and correspondences in Traditional Chinese Medicine (Huan, Rose, 2001) 61
Fig. 22 The diagram of multiple subsystems and the dynamic hierarchy in the Acupuncture Theory (the original illustrations of Acupuncture System is made by Min-Tung Chen, 2000) 63
Fig. 23 The diagram of Dynamic Multi-Agent System (DMAS) 64
Fig. 24 The optimization diagram of Intelligent Home Care Environment (IHCE) IA 66
Fig. 25 The space composition of the proposed Intelligent Home Care Environment (IHCE).... 67
Fig. 26 Lawton and Nahemow’s Press-Competence Model (Lawton & Nahemow, 1973; Satariano, 2006) 68
Fig. 27 The diagram of Actor-Network Theory (ANT) 69
Fig. 28 The diagram explaining how the system diagram is associated with the scenario table to demonstrate system testing with scenarios chronologically. 84
Fig. 29 Intel Infoscape Multi-touch Wall (Darren Murph, 2010) 86
Fig. 30 Woven QR Code designed by Trekky (Trekky, 2011).. 86
Fig. 31 Smart Woven Labels by *Quality Woven Labels,* NY (Woven Quality Labels, 2013). 86

Fig. 32 The Smart Laundry System 87
Fig. 33 The Smart Dressing System, Living 3.0, Taipei, Taiwan, 2012........ 88
Fig. 34 The Conceptual Smart Refrigerator (Kee, 2010)........ 89
Fig. 35 The diagram of system testing for Scenario 01 90
Fig. 36 The diagram of system testing for Scenario 02 98
Fig. 37 LED Lighting system 101
Fig. 38 Falling Monitoring System........ 103
Fig. 39 The diagram of system testing for Scenario 03 103
Fig. 40 The diagram of system testing for Scenario 04 106
Fig. 41 The conceptual diagram of Smart Sofa 110
Fig. 42 The diagram of system testing for Scenario 05 (Portion A)........ 111
Fig. 43 The diagram of system testing for Scenario 05 (Portion B)........ 113
Fig. 44 The diagram of system testing for Scenario 05 (Portion C)........ 115

List of Tables

Table 1 Comparisons and critiques of different approaches of intelligent environments 9
Table 2 The comparison of taste between three different health cares.. 23
Table 3 The objectives and IHCE assistance of scenarios... 31
Table 4 The list of design criteria for the system evaluation.. 31
Table 5 The patient profile.. 34
Table 6 The profile of four caretakers 35
Table 7 The evaluation of food service... 35
Table 8 The evaluation of dressing service... 36
Table 9 The evaluation of bathing service 36
Table 10 The evaluation of medication services... 36
Table 11 The supportability of pragmatic objects 36
Table 12 The supportability of symbolic objects... 37
Table 13 The supportability of aesthetic assemblage 37
Table 14 The format of knowledge base for the home care service profile 42
Table 15 Personal taste profile... 43
Table 16 Comparison between eastern and western cultures (eye contact and facial expression)44
Table 17 Comparison between eastern and western cultures (gestures and tone of voice).......... 45
Table 18 Comparison between eastern and western cultures (physical contact and psychological care).. 45
Table 19 Cultural evaluation form for the patient in home care.. 46
Table 20 Interview instrument of HANS with chosen categories 49
Table 21 Statistical Data of physical functioning in HANS... 51
Table 22 Statistical Data of symptoms and ailments/ medical condition in HANS 51
Table 23 Statistical Data of cognitive functioning in HANS 52
Table 24 Statistical Data of general feelings in HANS 52
Table 25 Statistical Data of social networks and IADLs in HANS... 52
Table 26 Statistical Data of physical performance in HANS 53
Table 27 Comparison of statistical data regarding self-assessment and direct measurement 54
Table 28 Sample subject: Type 01... 55
Table 29 Sample subject: Type 02... 55
Table 30 Sample subject: Type 03... 56
Table 31 Sample subject: Type 04... 57
Table 32 The overview of scenarios 82
Table 33 Types of computational systems and smart appliances/ HCIs in the scenarios............. 83
Table 34 The subject profile of Scenario 01 and 02 85
Table 35 The Scenario 01: Dressing/ Bathing/ Laundry 98
Table 36 The Scenario 02: Meal Preparation 100
Table 37 The subject profile of Scenario 03.. 101
Table 38 The Scenario 03: Fall monitoring 104

Table 39 The subject profile of Scenario 04 105
Table 40 The Scenario 04: Suspicious Events Monitoring 108
Table 41 The subject profile of Scenario 05 109
Table 42 The Scenario 05-A: Multiple Activity Scenario 113
Table 43 The Scenario 05-B: Multiple Activity Scenario 114
Table 44 The Scenario 05-C: Multiple Activity Scenario 116
Table 45 System Evaluation Criteria 117
Table 46 System testing & evaluation of Scenario 01: dressing/ bathing/ laundry 120
Table 47 System testing & evaluation of Scenario 02: meal preparation 123
Table 48 System testing & evaluation of Scenario 03: fall monitoring 125
Table 49 System testing & evaluation of Scenario 04: suspicious events monitoring 129
Table 50 System testing & evaluation of Scenario 05: Multiple activity scenario (Portion A) . 132
Table 51 System testing & evaluation of Scenario 05: Multiple activity scenario (Portion B).. 134
Table 52 System testing & evaluation of Scenario 05: Multiple activity scenario (Portion C).. 137

Chapter I

Introduction to Research Issues

This chapter introduces current issues in physical environments and home care services, and defines research questions accordingly.

1.1 Issues in Physical Environments

1.1.1 Buildings are static, whereas human needs change dynamically. Once artificial environments are built, they become "frozen" and their ability to respond dynamically to changing activities and multiple social/cultural behaviors diminish.

"Architecture is frozen music," the adage goes. When environments are built, they cease to evolve, yet they are expected to support dynamic activities and multiple purposes for many decades. Some built environments may be modified through remodels or repairs in response to the changing requirements of the occupants, yet the process of remodeling/ repairing is passive, time-consuming, and expensive (Brand, 1994). A well designed built environment should be able to support specific activities, but as these activities change over time while the original built environment remains "frozen" (Kalay, 2004), the fit between the environment and the users diminishes. In addition, multiple activities might be held simultaneously in the same place during different timeframes in a day, requiring different built environments.

1.1.2 To increase the fit between the built environments and their human occupants, either the buildings or the people who occupy them must adapt. Yet built environments have limited capacity for change, while human have limited ability for adaptation.

Once these frozen artificial environments no longer meet user's demands, an adaptation between the building and its human occupants is required in order to keep the evolving interaction in balance (Fig. 1). Built environments are designed with limited affordance to support certain activities. To increase the built environments' capacity for adaptation typically requires expensive retrofit or complete replacement. On the other hand, the user has limited ability for adaptation, especially as they age (Lawton & Nahemow, 1973). Their adaptation typically takes the form of manual assistance (hiring a personal attendant), which is expensive and can raise social and cultural conflicts (S. Montauk, 1998), or moving to a nursing home, which is expensive and has serious social/psychological consequences (Harris, 1994; S. Montauk, 1998).

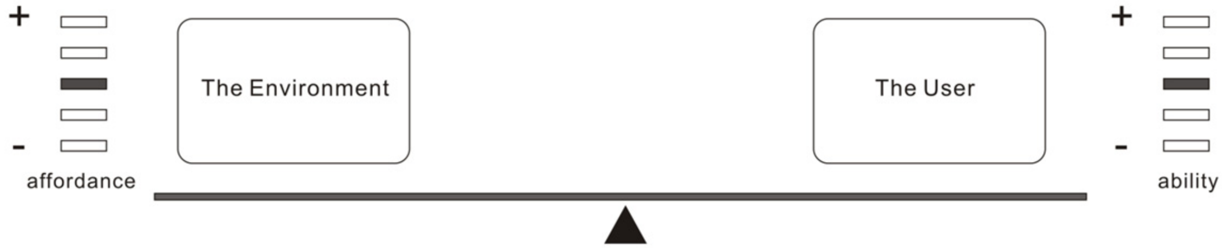


Fig. 1 The diagram explains the idea of the environment and users being in balance.

1.2 Issues in Home Care

1.2.1 Home care is the most prevalent way of bridging the gap between the needs of the elderly and the affordances of their home, in the form of in-person assistance from caregivers. However, conflicts frequently arise between caregivers and their patients owing to diversities of social and cultural backgrounds.

Due to the increasing prevalence of chronic disease, rising hospital costs, and an aging population, home care is one of the fastest-growing expenses in the Medicare program (S. Montauk, 1998). Caretakers have the closest, most direct contact with patients in home care. Home care involves helping patients (usually the elderly) with the basic activities of Daily Living (ADL)(Katz, Ford, Moskowitz, Jackson, & Jaffe, 1963) and Instrumental Activities Daily Living (IADL) (Lawton & Brody, 1969).

Nevertheless, when caretakers step into patients' houses, they are exposed to their patients' social and cultural territories/ boundaries as well as customs. Any differences in these customs between caretakers and patients will affect their relationship. For instance, in Asia, due to a shortage of nursing professionals, more and more immigrant workers are hired from developing countries to work as caretakers. The immigrants receive only minimal training, mainly focusing on general, standardized physical nursing skills. Yet the training often neglects the uniqueness of human beings—each patient has specific tastes (Cranz, 2004) based on his or her social and cultural backgrounds[1].

Thus, the drawbacks for having assistant caretakers are: 1) the high costs and low availability of caretakers; 2) caretakers' limited knowledge about patients' History of Present Illness (HPI) and personality (an inability to provide appropriate psychological support); 3) patients' difficulty communicating with caretakers due to social, cultural, and language differences; (4) the inadequateness of the home environment to afford multiple adults, with different social/cultural customs, living together in close proximity.

[1]According to Galen Cranz's theory of taste, ***Taste= (Pragmatics + Symbols) Integrated Aesthetically*** (Galen Cranz, "A New Way of Thinking about Taste," *The Nature of Craft and the Penland Experience* (Lark, NY, 2004), pp. 130-136).

1.2.2 In home care, existing built environments cannot provide enough flexibility in response to the changing physical/psychological functioning of the elderly.

Becoming less physically and mentally able is among the essential challenges of aging. When people are growing older, their physical/ psychological status will not be constant and the variations might be larger than any other phases in life, e.g. being teenagers (Satariano, 2006). According to the Disablement Model, the process is initiated by a pathology with an associated level of physiological or cognitive impairment that may lead, in turn, to functional limitations and, ultimately, to a disability (Ferrucci et al., 1996; Satariano, 2006; Verbrugge & Jette, 1994).

Aside from the variation owing to the process of aging/ disablement, the elderly's physical and cognitive functioning might be varied as well. The current services in home care environments are twofold: 1) physical functioning and 2) cognitive functioning.

1) Physical Functioning

In the domain of gerontology, physical functioning can be measured in terms of Activities of Daily Living (ADL) (Katz et al., 1963) and Instrumental Activities Daily Living (IADL)(Lawton & Brody, 1969). These are widely accepted as the key ability of having an independent life in gerontological studies. While ADL is designed to assess independence in areas of self-maintenance, IADL assesses ease in adaptation to the environment

A. Activities of Daily Living (ADL)

- necessary for Independent living
- designed to assess independence in areas of self-maintenance
- E.g. bathing, dressing, using a restroom , transferring from a bed to a chair, continence, and feeding

B. Instrumental Activities of Daily Living (IADL)

- higher levels of functioning than ADL
- designed to access ease in adaptation to the environment
- include a number of different capacities, such as physical and cognitive abilities, as well as access to personal and social resources
- E.g. Housekeeping/ home maintenance/ telephone use/ shopping/ food preparation/ laundering /use of transportation/ use of medicine/ financial management

2) Cognitive Functioning

Cognitive functioning refers to the psychological issues involved in home care services. In gerontology, cognitive functioning could be discussed in three areas: sense of control, sense of coherence, and self-efficacy.

A. Sense of Control

Sense of control is a generalized sense of being able to access or associate with daily events confidently. Social epidemiology, explains the association between a variety of social factors, such as socioeconomic status and social networks, and different health outcomes (Syme, 1989).

B. Sense of Coherence:

Sense of coherence is defined as a generalized sense of understanding events in everyday life as well as a sense of optimism that future events would unfold as well as one could expect (Antonovsky, 1979).

C. Self- Efficacy:

Self-efficacy is a sense of confidence and competence (Antonovsky, 1979). It is also a belief in one's capabilities to organize and execute the courses of action required to produce given attainments (Bandura, 1997). Self-efficacy is perceived as being specific to particular tasks, especially physical activity (Satariano, 2006).

The aforementioned variations in the disablement process and physical/cognitive functioning of the elderly change dynamically. However, once physical environments are built, they remain static and cannot provide enough flexibility in response to the ever-changing requirements of the user under in-home care treatment.

1.3 Research Questions

This research mainly explores: How can built environments be designed to be dynamically responsive to ever-changing human needs and multiple social/cultural behaviors, so they stay in balance with the changing needs and abilities of people, especially in case of elder care? Based on the aforementioned problems, the major research questions are as follows:

- ***Questions in Physical Environments***
  1. How can built environments be made responsive to ever-changing human needs and multiple social /cultural behaviors?
  2. How can built environments respond to human needs from a holistic viewpoint?

The above questions lead to several sub questions, e.g. to what degree should the built environment be responsive, and how frequently should built environments interact with their occupants?

- ***Questions in Home Care***
  1. How can built environments in home care help to reduce conflicts that arise between caregivers and the elderly owing to a diversity of social and cultural backgrounds?
  2. In home care, how can built environments provide enough flexibility in response to the changing physical/psychological functioning of the elderly?

To further research and investigate these questions, this research proposes Intelligent Home Care Environments as a solution. Accordingly, reviews of the development of intelligent environments are necessary. Chapter II explores the origin and essence of intelligent space, criteria of intelligent agents, and how an intelligent environment can be designed as living ecology. To answer how these questions can relate to and be applicable to home care, a review of current solutions in home care services is required and will be addressed in Chapter III.

PART I

Literature Review

Part I reviews the literature in two different fields: 1) intelligent environments and 2) home care environments. Chapter II turns to the history of intelligent environments, including the origin, current approaches, and how to design an intelligent environment as a living system. Chapter III looks into the development of home care environments, covering issues of aging in gerontology, as well as related research.

Chapter II

Design Intelligent Environments as Living Ecology

This chapter provides background information about the development of intelligent environments from nascent technologies to a vision of the future, including the origins of responsive environments, and current approaches and limitations. The section also discusses the interaction between intelligent environments and users, and the idea of designing intelligent environments under the rubric of living ecology.

2.1 Intelligent Environments

2.1.1 Idea of Intelligent Environments

The concept of making environments intelligent was first proposed by Nicholas Negroponte (Negroponte, 1970, 1975). He proposed an intelligent, self-cognizant environment that could serve its occupants. Through recognition and various degrees of responsiveness, "responsive architecture" could monitor, study, and adapt to every occupant's needs, not only with regulatory controls but also through a larger, intelligent system. Architecture could not only satisfy the needs of multiple activities, but also mediate between its inhabitants and the external environment. The habitat itself will respond to human needs, instead of humans designing their habitat. These ideas are continued by William Mitchell in *City of Bits*, *e-topia*, and *Me++* (Mitchell, 2000a, 2000b, 2004), an informal trilogy of books which examines the ramifications of information technology in everyday life. These conceptual notions are mainly drawn from two scales of discussion: 1) integration systems; and 2) specific control facilities.

2.1.2 Current Approaches

The current approaches to intelligent environments can be categorized from three perspectives: 1) integration systems; 2) specific control facilities, and 3) E-life house.

A. Ubiquitous Computation – Network and Integration Systems

An example of the integration of intelligent facilities and control systems in intelligent houses is found in Ken Sakamura's designs. He uses an open-source microprocessor operating system called TRON to connect objects in a house through Ucode ID tags, creating an integrated environment (Sakamura, 1996). It not only allows identification and communication among objects in the building, but also can be inserted into physical cities as well. If Ucode ID tags were scattered in the physical environment, the houses and the city itself could be made responsive to occupants' needs. However, this system treats each Ucode ID as an independent microchip and is unable to reflect the unique contexts of different environments nor the sensations and comforts of individual occupants (Takeyama & Sakamura, 1989).

B. Specific Control Facilities

The Center for Building Performance and Diagnostics (CBPD) at Carnegie Mellon University, directed by Volker Hartkopf and Vivian Loftness, focuses on building performance with evaluation methods (Hartkopf, Loftness, Mahdavi, Lee, & Shankavaram, 1997). The Advanced Building Systems Integration Consortium (ABSIC) pays attention to the impact of advanced technology on the physical, environmental, and social settings in office buildings in order to create high-performance work environments. Applying total building performance can reduce energy consumption, pollution, and waste in existing and new construction and simultaneously improve the quality of life within buildings as measured through occupant satisfaction, health and productivity.

Regarding the flexibility of housing, M.C. Mozer proposed "The Adaptive House" an integrated system within a home that essentially programs itself by observing the lifestyles and desires of the inhabitants and learns to anticipate their needs (Hartkopf et al., 1997; Mozer, 1998, 1999). ACHE includes a neural network and relies on reinforcement-learning techniques (Sutton & Barto, 1999). The intelligence of this house lies in its ability to adapt its operation to accommodate the inhabitants' lifestyles. Inhabitants need not adjust facilities via a specific interface. Instead, the house itself learns the behaviors and makes the necessary changes to fit inhabitants' needs. The objectives of the system are to anticipate the inhabitants' needs and to minimize the combined costs of discomfort and energy.

C. E-Life House

Applying ubiquitous computation and smart appliances and equipment, some research projects pursue a so-called "e-life house," such as the *365 days Ambient Intelligence Research* by Philips Research Home Lab (de Ruyter, 2003), *Toyota PAPI Dream House* by Toyota Home and Ken Sakamura (Doi et al., 2005), *SamSung Homevita* (SamSung, 2007), and *Living 3.0* in Taiwan (Chen, Ma, Jeng, & Chang, 2010; The Architecture and Building Research Institute, 2009). The general characteristic of these approaches is that the house is heavily adapted to create a 'digital fabric network' and integrate most of the electronic equipment, e.g. HVAC system, appliances, etc. in a home.

The goal of this approach is to pursue an "e-live style" that benefits from advanced technologies. Some projects declare specific sub-goals, e.g. health, sustainability, and convenience (Chen et al., 2010). Nevertheless, there is no discussion about the interrelationship between these sub-goals. They become problematic once these goals conflict. Besides, it is unclear which priorities take precedence among these sub-goals when among different users. Another unanswered issue with this approach is that it lacks both a social and cultural discussion of human behavior.

D. Limitations of Current Approaches

The aforementioned research is based on technical strategies and are, mostly, ad hoc solutions. Based on conventional cybernetic principles, they emphasize physical building facilities instead of the dynamic interrelationships between occupants and built environments.

This research was carried out mostly on static buildings and passive facilities that are still unable to interact with the changing demands of occupants and environments. Meanwhile, the aforementioned research may partially fulfill inhabitants' physical needs but might neglect other psychological issues, e.g. the social and cultural influences on human sensation and expectation (Brager & de Dear, 2003). For instance, occupants might feel tired of extremely homogenous or standardized interior environments, leading to dissatisfaction. In the meantime, the built environments cannot solve conflicts among multiple users and activities in the same space at the same time. There is no holistic balanced control solution that both provides flexibility to the occupants and addresses conflicts in built environments. The limitations of prior approaches could be summarized as follows:

- Lack of discussion of the dynamic interrelationships between occupants and built environments
- Failure to propose conflict solutions between simultaneous multiple users and activities at the same space/ time
- Neglect of the psychological issues of occupants according to social and cultural factors, e.g. personal and cultural taste.

2.1.3 Comparisons and Critiques of Current Approaches

The comparisons and critique of aforementioned approaches to intelligent environments can be summarized as shown in Table 1. The comparisons focus on types of intelligent environments, project goals (what kinds of assistance does the system/ technology purpose), solutions (how different projects accomplish their goals), and limitations/ drawbacks (Chen et al., 2010; de Ruyter, 2003; Doi et al., 2005; Georgia Tech., 2005; Helal et al., 2005; Intel_Proactive_Research, 2004; Larson, 2002; Mozer, 1999; Sakamura, 1990, 1996; SamSung, 2007; Steinfeld, 1975, 1979; Story, Mueller, & Mace, 1998; The Architecture and Building Research Institute, 2009; The Aware Home Research Institute (AHRI), 2002)

Year	**Project**	**Type**	**Project Goals** (what kinds of assistance)	**Solutions** (how the project is accomplished)	**Limitations and drawbacks**
1950s/ 1985	Barrier-free/ Universal design	• Objects • vehicles • Interiors • Architecture • Landscapes • Urban design	• Remove the barriers from the physical environment • Help the user to gain full access to the physical environment	• Provide a standardized solution that can fulfill as large a scope of human demands as possible in terms of gender, age, ethics, etc.	• Some design criteria conflict each other • Neglects uniqueness of individuals

					• Solutions are static or semi-static • Removing too many barriers might create an imbalance between the environment and people
1988	TRON project, TRON Intelligent House (by Ken Sakamura)	• Infrastructure (TRON project) • Smart house	• Allows identification and communication between objects and the user • To create fusion of humans, nature and computers • Convenience • Security	• Open-source microprocessor operation system • Ucode ID Tags • Computerized facilities • External and international information network available for each room	• Neglects uniqueness of individuals, e.g. desired personal comfort/ sensation level
1998	The Adaptive Control of Home Environment, ACHE (by M.C. Mozer et al.)	• Smart house	• Adapt its operation to accommodate the user's lifestyle • Learn the user's preference through their manual adjustment of lights or thermostats	• A neural network • An intelligent control system • Reinforcement-learning technologies	• Lack of social/cultural discussion • Neglects discussion of casual relationship between the user and their behavior
2002	House_n Project (in MIT Media Lab by Kent Larson et al.)	• Open source buildings • Smart house	• Individuals could be designers/ builders • Healthy living (creating healthy environments and encouraging healthy behaviors) • Energy efficiency	• Pervasive computing • Scandalized architectural and technical components • Digital infrastructure • Sensing, Interface, and Just-in-time Information	Lack of discussions of: • Social/cultural issues • Behavior conflicts • Causality of the user's activities
2002	The Aware Home, AHRI (by Georgia Tech.)	• Smart house • E-health care	• makes real-life meal recommendations to its users based on their health and taste profiles • Early Detection of Developmental Delay • Facilitating Reflection in Individual Diabetes Management • Sympathetic Devices • Learning tools (the Helping Hand)	• Domestic technology • Positioning of power lines • chronic care managements, • digital entertainment and media	Lack of • An integrated system of the entire intelligent environment • Discussion or optimization between multiple sub-goals • Social/cultural discussion
2002	365 day's Ambient Intelligence Research (by Philips Research Home Lab)	• Smart house	To Fulfill three types of user needs: • Need to belong and share experiences • Need to balance and organize life • Need for thrills, excitement, and relaxation	• Virtual place network • Intelligent appliances • Ambient intelligent lighting • Intelligent remote control	Lack of discussions on: • Social/cultural issues • Behavior conflicts • Causality of user activities
2004	The Center for Aging Services Technologies , CAST (by Intel Proactive Research & university researchers)	• Smart house • E-health care	• Detects, monitors and records the daily living activities of an elder • Helps manage everyday activities so that the elders' independence is maintained while relieving some of the burden on around-the-clock tasks of caregivers	• Sensor Networks • Collects data through postage stamp-sized wireless Radio Frequency Identification (RFID) tags affixed to household objects • Virtual monitoring center.	• Lack of cause-and-effect discussion between activities and user's demands

2005	Toyota PAPI Dream House (by Toyota Home K.K. and Ken Sakamura)	• Smart home	• Reduces harm to the environment • Energy efficiency • Increases the comfort and security of the residents • Improves cross-platform internetworking	• Modular home construction techniques • Ubiquitous network • Ubiquitous communicator • Intelligent remote controller • Smart appliances	Lack of discussion on: • Social/cultural issues • Behavior conflicts • Causality of user activities
2005	The Health Systems Institute, HSI (by Georgia Tech. and Emory Univ.)	• E-Health care • Integrative Patient-Centered Systems • Pediatric Care, Health and Wellness • Chronic Care and Disease Management • Sustainable Aging • Home Health / Telehealth • Reimburseme nt and Payment Systems	• Adjustable patient room • Accessible Bathroom • Balance between Privacy and surveillance • The facility-integrated chair (The Triage Chair) • Family-link robotics (psychological compensation)	• Biostatistics and Data Management • Healthcare Robotics • Healthcare Environments	• Some technologies are passively reactive • These advanced technical systems cannot function until the facilities are manipulated correctly. • The user might have difficulty utilizing these facilities at home, especially during an emergency. • Lack of an integrated system of the entire intelligent environment
2007	• Samsung Home vita • LG HomeNet • SK Telecom Ubiquitous Dream Hall • Ubiquitous Gallery • Haustory (in Korea)	• Multi-scale ubiquitous E-Life (smart living) • (Anyone/ Anytime/ Anywhere/ Any media/ Any service)	• Comfort • Convenience • Entertainment • Safety	• Home network • Smart facilities • Intelligent appliances	Lack of discussion on: • Social/cultural issues • Behavior conflicts • Causality of user activities
2009	Gator Tech Smart House (by Mobile and Pervasive Lab, U. of Florida)	• Assistive environments for successful aging	• Location tracking • Activity monitoring	• Assistive technology • Sensor networks • Radio-frequency identification (RFID) system • Location tracking system (smart floor) • Real-world modeling for remote monitoring	• Privacy issue • Inaccuracy of real-world modeling representation (the user's behavior cannot be represent exactly through a virtual model)
2009	Living 3.0	• E-Life (smart living)	• Safety • Healthy • Sustainability • Convenience	• Smart materials • Sensor networks (IP sensing monitoring system) • Information display (the Brief Wall) • Intelligent appliances (I Tea Table) • Smart HVAC system	Lack of discussion on: • Behavior conflicts • Causality of user activities • Social/cultural issues

Table 1 Comparisons and critiques of different approaches of intelligent environments

2.2 Rationale of Intelligent Environments

With advanced hardware and software technologies, researchers are developing computational models of intelligence in artificial systems. Artificial Intelligence (AI) is already an integral part of various products - including PDAs, PCs, and industrial machines, and is expected to become an essential fixture of future environmental design.

According to Nicholas Negroponte's theories (Negroponte, 1970, 1975), Intelligent Environments passively sense users' activities and are capable of actively participating and interacting with occupants' activities without being commanded. According to Johnson's theory (1971), an intelligent space should have self-organizing controllers that automatically sense occupants' demands, make judgments, and adjust built environments to fulfill occupants' requirements. Therefore, an Intelligent Environment should be able to recognize user identification, distinguish the changes of users' demands and behaviors, and finally modify the environment to adjust to these changes. Since the early 1970s, the research focusing on the development of Intelligent Environments have progressed from smart objects (e.g. thermostats, building security, automatic doors) to building-scale intelligence (Kalay, 2004).

2.3 Interaction between the Environment and the Occupant

Endowing the physical environment with artificial intelligence requires mediators to assist in the interaction between that environment and users. Intelligent environments generally require a so-called "intelligent agent" (IA) to act as an interface enabling the intelligent environment to provide more flexibility and adaptability to the user according to ever-changing activities. To discuss the characteristic of an IA, we could begin with the discussion of an "agent."

2.3.1 What Is an Agent?

An "agent" is defined diversely in different principles. In terms of intelligent environments, an agent is generally understood as a mediator between two entities. It is software situated in an environment. An agent is the basic component of artificial intelligence that perceives its environment through sensors and acts upon its environment through actuators (Norvig, 2003) (Fig. 2). In other words, an agent receives information (percepts)[2] and chooses actions[3] to perform through actuators that affect the environment. These repeated steps formulate the execution cycle of an agent (Norvig, 2003; Padgham & Winikoff, 2004).

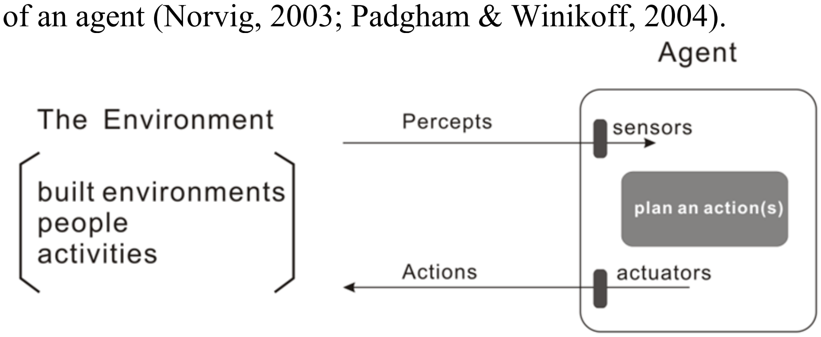


Fig. 2 Interaction between the environment and an agent

[2] A percept is an entity of information received from the environment through some sensors (Russell & Norvig, 1995, Padgham & Winikoff, 2004).

[3] An action is an agent's ability to affect its environment (Norvig, 2003; Padgham & Winikoff, 2004).

2.3.2 When Can an Agent Be Considered "Intelligent?"

When we discuss the intelligence of an agent, the agent obviously requires certain attributes for it to be considered "smart." An intelligent agent (IA) is not only a computer system situated in the physical environment, but also a system capable of autonomous action in this environment in order to meet its design objectives (Wooldridge and Jennings, 1995). It should be autonomous, have goals and intentions, and communicate with other such agents to perform cooperative problem solving. An IA is different from conventional software in that they are long-lived, semi-autonomous, proactive, and adaptive (Software Agents Group, MIT).

After receiving a series of information through sensors, an IA can record information as "an event." After accumulating various events, it formulates a knowledge base. Based on the knowledge base, these events are analyzed and understood by the IA. Consequently, the IA can propose a goal to react to these events (usually solving the problem). To achieve the goal(s), the IA can formulate a scheme (sub-goals) for execution. Finally, these actions could be physically performed through actuators to affect the physical world (Fig.3).

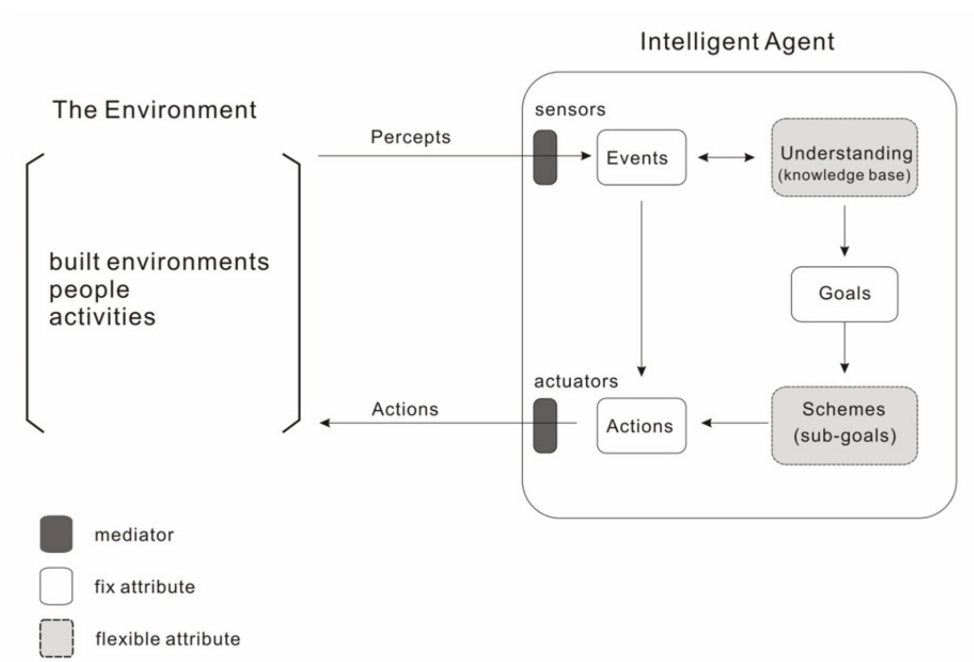


Fig. 3 Interaction between an intelligent agent and the environment

To consider an agent being intelligent, there are some capabilities an IA should have (Wooldridge, 2002; Padgham & Winikoff, 2004):

- Reactive: to respond to ever-changing events/ activities dynamically
- Proactive: to propose plans to pursue goals persistently
- Social: to commutate/ cooperate with other IAs to formulate a society of IAs in order to achieve common goals (Minsky, 1988)
- Autonomous: to execute independently instead of being manipulated externally
- Flexible: to provide multiple choices to achieve goals

2.4 Fundamental Composition of Intelligent Environments

The fundamental composition of an intelligent environment has three parts: the built environment, the user, and the interface (Fig. 4). The built environment is composed of multiple objects, e.g. structure, walls, furniture, heating, ventilation, and air conditioning systems (HVAC), etc. The interface, usually the IAs and related facilities, e.g. sensors and actuators, are the connections between the occupants and the built environment.

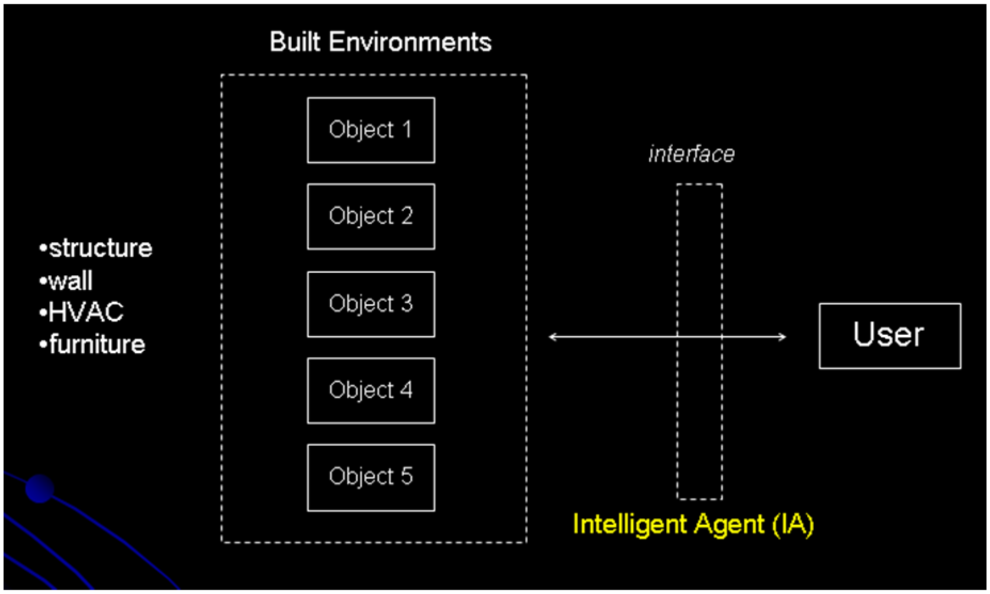


Fig. 4 The fundamental composition of intelligent environments

Utilizing sensors and microchips embedded into built environments to observe and record occupants' behavior, an intelligent environment considers data as computational parameters for occupant-behavioral learning (problem identification), the anticipation of user demand and behavior modes (goal formulation), and the adjustment of specific technological facilities to fulfill these demands (solution synthesis).

2.5 Agent-Based Intelligent Environments

Current approaches of implementing intelligent environments with IAs are 1) single super intelligent agents and 2) multiple intelligent agents.

2.5.1 Single Agent-Based Intelligent Environments

The single intelligent agent proposes using a powerful intelligent processor (centralized IA) that integrates and analyzes all collected data and proposes possible actions. This approach builds on top-down Artificial Intelligence theories but has a major restriction – a single super intelligent agent will be overloaded dealing with continuously changing variables due to dynamic living environments and complex human behaviors (Fig. 5).

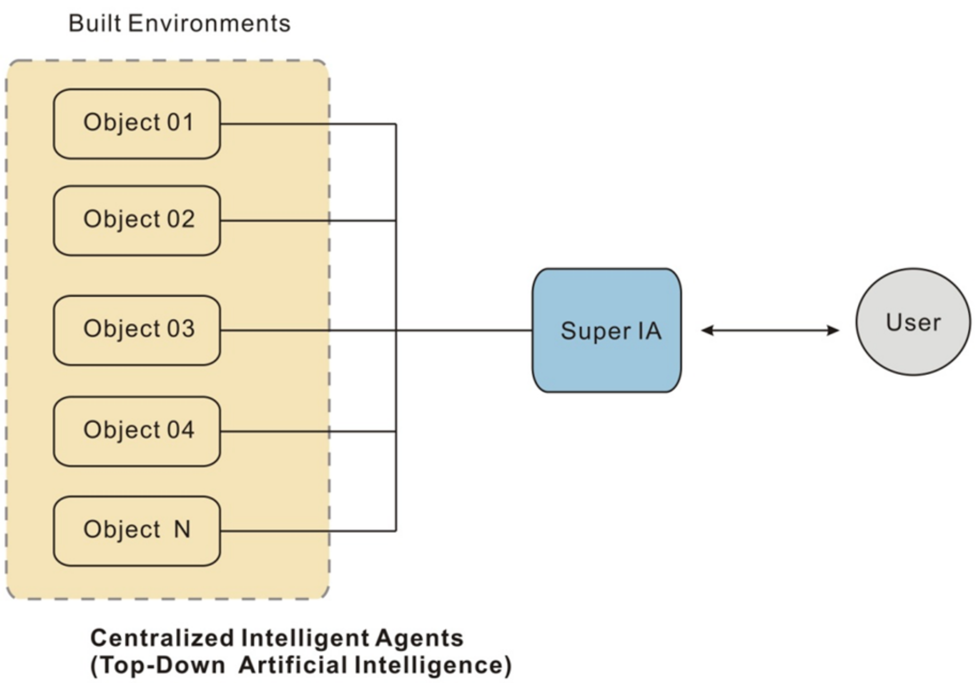


Fig. 5 The composition of centralized intelligent agent system

One of the most representative examples of the centralized IA is the domestic robot. Since a built environment is constructed for human beings, the major task of robot design is to make the robot fit into our existing environments. The more it fits, the less disruptive it is to the environment. For instance, in order to hold various cups made of different materials, robots must identify the objects and adjust their actions accordingly. Lifting a large ceramic mug requires similar, but not the exact same skills as raising a Styrofoam cup. Because of this wide variation, even in simple tasks, it usually requires too much effort to make a robot learn specific tasks.

For instance, the Healthcare Robotics Group at the Georgia Institute of Technology proposes a biologically inspired assistive robot capable of obeying verbal commands and exploiting the physical environmental modifications and accomplishing tasks similar to those completed by a service dog (Kemp et al., 2008). The healthcare robot can be directed by giving a subset of the 71 verbal commands command and illuminating a task-relevant location with a green laser pointer or colored towels. In order to direct the robot to open the doors and drawers for the user in healthcare, the physical objects, e.g. handles, need to be tied with colored towels (Fig. 6).

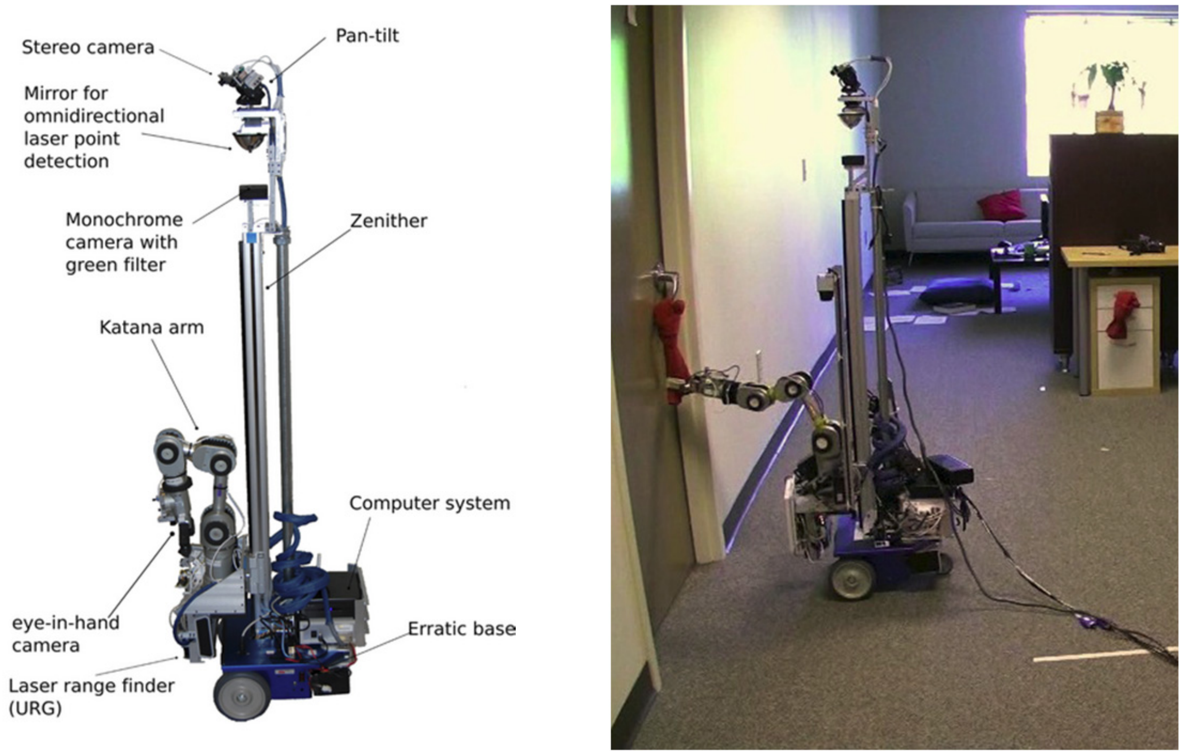


Fig. 6 On the left, the composition of the assistive heal care robot. On the right, the assistive robot helps the user to open a door with the handle tighten with a colored towel.

Although the assistive robot can respond to verbal commands, it still cannot manipulate the handle of the door and drawer originally designed for human beings. In order to allow the assistive robot to open the door, the handle needs to be affixed with a red towel so that the robot could pull it down to manipulate.

Besides, it has been devoted a lot of efforts and budgets to research a assistive robot to locate itself and execute just a simple action-- pull the colored towel. If the ultimate goal is to have an assistive healthcare robot that can help the user's multiple daily activities, it might cost much more and longer than the current assistive robots do.

2.5.2 Multi Agent- Based Intelligent Environments

Multiple intelligent agents can overcome the main drawback of single super IA. They share information collected from the built environment between multiple intelligent agents (distributed IA). Each IA only deals with individual situations and can cooperate with other IAs should any conflict arise (Fig. 7).

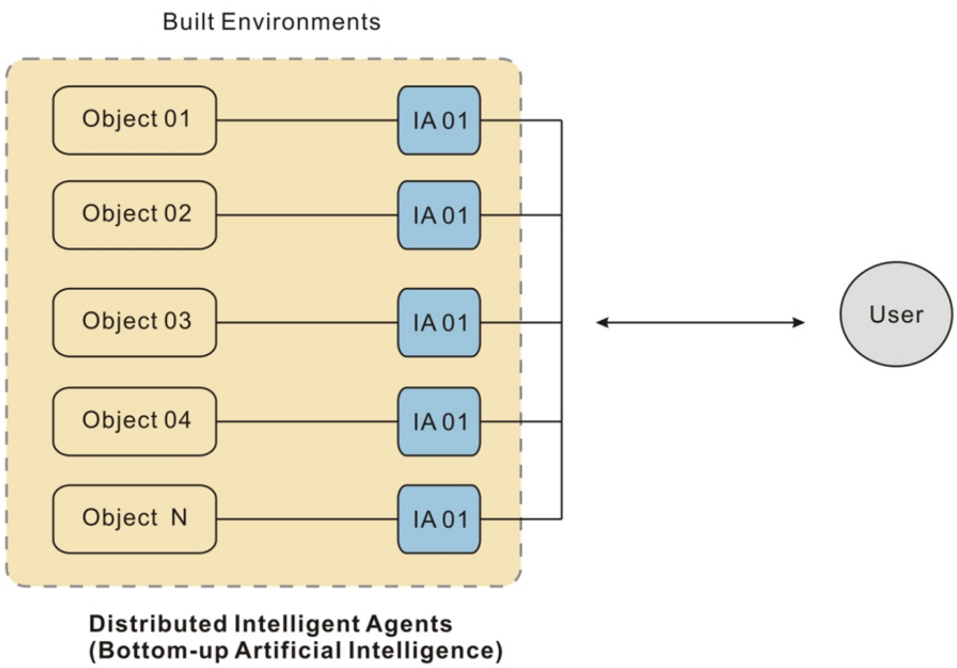


Fig. 7 The composition of a distributed intelligent agents system

Nevertheless, since the cooperation between multiple IAs is based on protocols according to the hierarchy of the system, once the hierarchy is fixed, the cooperation is confined accordingly. For instance, if conflicts arise between IAs that are not connected in the hierarchy of the system, these IAs might not be able to cooperate. Even more, if the conflicts happen between IAs at the same level in the hierarchy, they have the same level of control authority and cannot provide an optimized solution to solve the problems.

2.6 Design an Intelligent Environment as a Living System

2.6.1 The Environment as Context

The intention of most environmental design is to meet the users' specific needs and to support related human activities. Nevertheless, once built, the artificial environments become static and difficult to be adjusted. The built environments only serve as passive backgrounds on which human activities occur. Even if the built environments could support the original expectation of clients, the built environment cannot adjust itself for the ever-changing activities of occupants. Instead, the occupants have to adjust their activities within the confines of the existing, static built environments.

For instance, a house is designed for a certain number of residents and specific activities. If the owner would like to create a home office, or host a weekly class in the house, there are plenty of objects, e.g. furniture, which must be rearranged every time those activities occur.

2.6.2 The Environment as a Machine

"The house is a machine for living in (Corbusier, 1923). " Take one step further from the passive built environments; designing the environment as a machine, like an automobile, creates a tool that can be used to augment or support certain activities initiated by the human. Nowadays, new technologies not only have spawned more advanced equipment capable of performing multiple functions, but also enable built environments to support multiple activities. However, in this concept, the technologies only allow the built environment to become a living machine that can be passively manipulated instead of reacting proactively. Meanwhile, the user and the built environment are considered separately without sufficient human-environmental interaction.

2.6.3 The Environment as Living Ecology

The aforementioned concepts of environmental design treat humans and the environment as two separate entities. How to improve the way human interact with the built environments more intimately?

Consider the environment and its inhabitants as a single living ecological system, as one entity. The concept of a living ecological environment is almost like a cyborg, an organism that has both artificial and natural systems, integrating different pieces that fit together to make a larger living system. From the medical viewpoint, conceptually, it is similar to the rationale of utilizing an artificial hand, an extension of the human body. The artificial object is so closely combined with the human body that the user could behave instantly and instinctively almost without any other interference.

However, practically speaking, adapting artificial devices may cause some issues. For instance, the user might feel uncomfortable to be closely connected to the artificial devices for a long period. From the development of artificial intelligence (AI), utilizing IAs embedded into the environment will make living places smarter by mimicking a manager/housekeeper for the occupants. The environment could consequently observe, analyze, and learn how occupants behave, thus anticipating and meeting the needs of the occupants. Consequently, the environment can initiate action on its own without being directly operated by occupants each time; namely, the IAs can assist in integrating human and artificial environments, treating them as the unit of analysis and action.

2.7 Conclusion

This chapter develops the idea of designing intelligent environments as Living Ecology from the perspective of human-environmental interaction. The brief history of evolution and current approaches regarding intelligent environments are reviewed as well, including the rationale for smart space and the criteria of intelligent agents. To answer the questions in home care proposed in Chapter I, the current issues in home care environments will be reviewed in the following chapter, including epidemiology of aging, comparisons among different medical organizations, and present approaches of home care services.

Chapter III

Home Care Environments

This chapter elaborates on the many current issues and challenges facing the home care services industry from various perspectives, including epidemiology of aging and gerontology, demographic shifts towards an older population and uncovers diverging strategies posited by different schools of thought in the medical field. The chapter also delves into the domains of home care service, and offers a critique of current solutions.

3.1 Issues of Aging

3.1.1 Epidemiology of Aging

Aging populations has become a worldwide issue. From a demographic viewpoint, if we compare the population structure of 1950 with that of 2030 both in the so-called developed and the developing worlds, the ratio of the population older than age 65 years old increased dramatically (United Nations, 1999; U.S. Census Bureau, 2000). To understand aging populations around the world, The Epidemiologic Transition Theory describes a variety of factors affecting aging populations as global patterns, e.g. demography, gerontology, and geriatrics.

3.1.2 An Ecological Model of Aging

To discuss epidemiology from a holistic viewpoint, the first ecological model (Fig. 8) is proposed to describe how patterns of health and well-being are affected by a dynamic interplay among biologic, behavioral, and environment factors (Smedley, Syme, Sampson, & Morenoff, 2000).

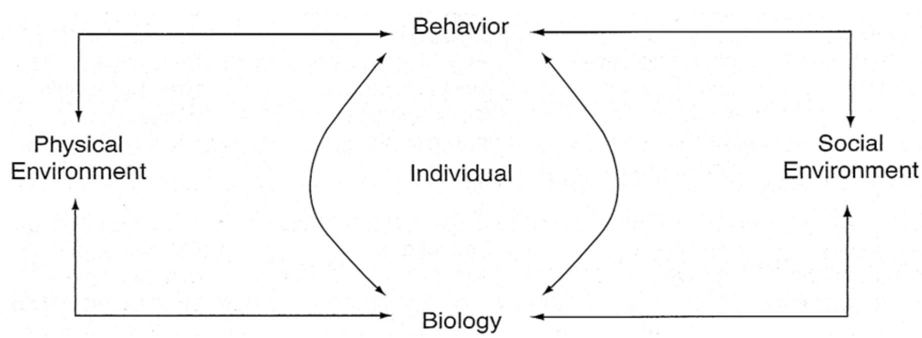


Fig. 8 The Ecological Model (from U.S. Department of Health and Human Services)

This model is developed to include more interrelated variables from a larger universe of inputs affecting the epidemiology of aging (Satariano, 2006). As shown in the ecological model (Fig. 9), physical environments correlate with many factors of aging, e.g. physical/ cognitive functioning, depression, disease and comorbidities, etc.

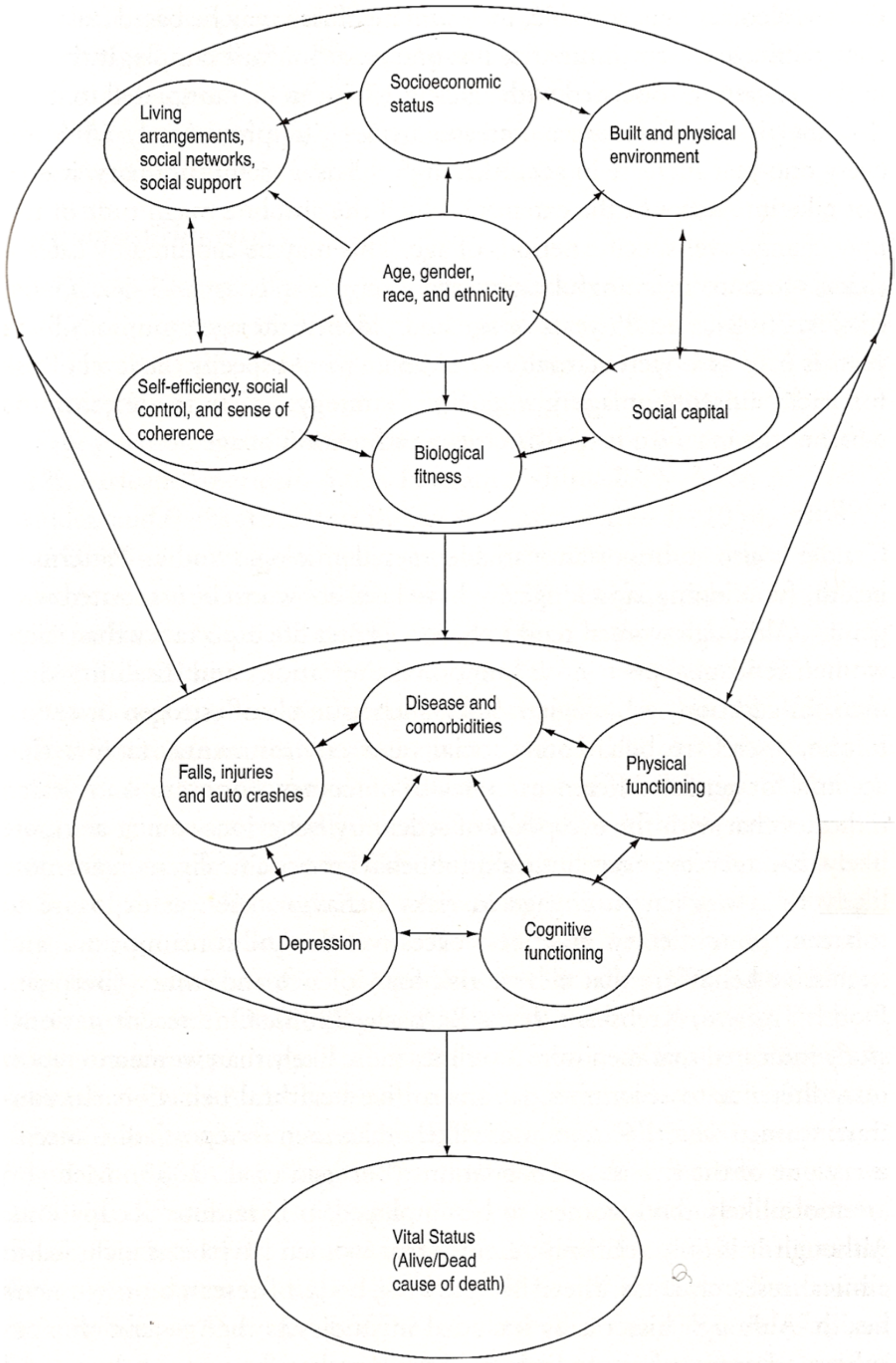


Fig. 9 The Ecological Model in epidemiology of aging (Satariano, 2006)

3.1.3 The Disablement Model

Given that becoming less physically and mentally able is among the essential issues in aging, in order to design a physical environment that can benefit the aged, we should discuss the process of disablement. From the Disablement Model (Fig. 10), the process is initiated by a pathology with an associated level of physiological or cognitive impairment that may lead, in turn, to functional limitations and, ultimately, to a disability (Ferrucci et al., 1996; Satariano, 2006; Verbrugge & Jette, 1994).

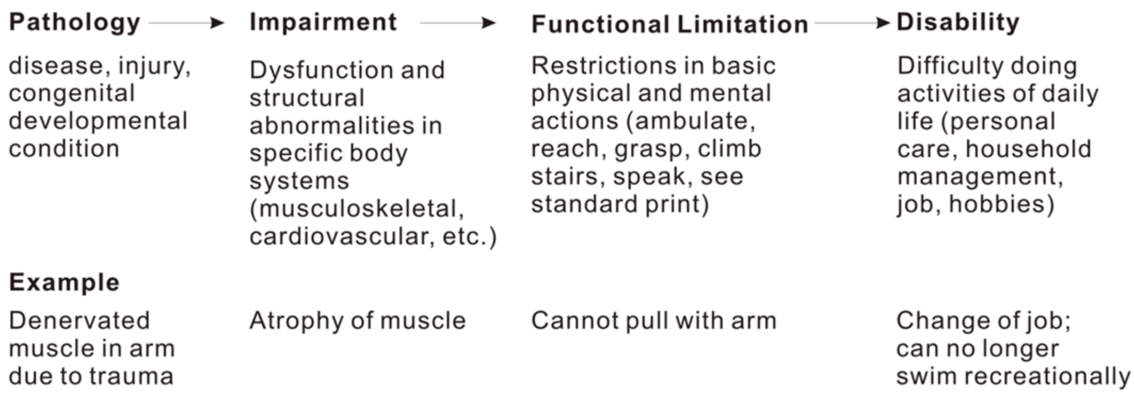


Fig. 10 The Disablement Model (Verburgge & Jette, 1994; Guralnik & Ferrucci, 2003)

Regarding the process of disablement, an ideal home care environment should be not only able to provide a non-toxic physical environment, but also capable of intervening or delaying the process of disablement to a certain degree. If the disability is an unavoidable process in aging, it is extremely favorable to maintain good living quality as long as possible, and postpone/ condense the disability to the very final stages of life.

3.2 Why People Choose Home Care

Home care benefits the patient in many ways, including economic savings and convenience. When people require health care, they not only need physical therapies but also psychological assistance. Patients' psychological status can change and weaken physical conditions do. The presence of family and friends along with familiar surroundings increases psychological comfort. Further, physical environments could also improve the patient's psychological status.

- **A "House" is a living container of the body while a "Home" is a place for both mind and the body**

A house mainly depicts the physical, material built environment for human bodies; in contrast, a "home" describes not only the physical substance, but also a place for the mind and soul. For instance, it is easy to build a physical environment that looks like the patient's house, but it is hard for others to recreate the familiarity and intimacy of a place for the patient without knowing the patient's behavioral patterns and aesthetic preferences.

■ **Taste as Personal Expression—Personal Style Assemblages**

Clare Cooper Marcus mentions in *House: As a Mirror of Self* (2006) that interior living environments not only reflect one's social and cultural backgrounds, but also contain comprehensive expressions of personal memories and psychological attributes. Designers should be attuned to inhabitants' taste, habits, mental sensibilities, and psychological susceptibilities (Abercrombie, 1977). These factors should be similarly respected and catered to by home care professionals. Patients can customize their interior environments to suit their tastes by arranging pragmatic and symbolic objects[4] in terms of their aesthetic standard. As outsiders to this environment, caretakers should not arrange the interior as the most convenient way for them to help the patient, but should respect and help the patient arrange the physical environment according to their taste that represents both personal expression and cultural norms.

3.3 Comparisons among Different Medical Organizations

Physical environments are arranged in different ways based on patients' functional and medical needs. These differences can be explored through the comparison of three types of health care organization: the hospital, the nursing home, and home care. Due to dissimilar levels and complexity of medical therapies, each type of medical institution has unique perspectives and emphases on the interior environment. At the same time, the flexibility and adjustability of living spaces varies among patients.

A. The Hospital

In the hospital, the complexity of medical therapies requires many pragmatic objects, e.g. medical equipment and facilities. Since "medical functions" are most essential for a hospital, the physical environment needs to be designed accordingly. Medical professionals have more say than patients do about the interior arrangement of hospitals. In this way, pragmatic objects become much more important than symbolic items. Further, any aesthetic integration heavily relies on standardization. For instance, the interior of a patient's room might be painted a pleasant color and have good light exposure because of standard rules of the entire hospital. Nonetheless, patients will not be allowed to adjust or choose different colors or styles based on personal or cultural taste. Thus, each patient's room might appear characterless, as if generated by mass production. Although some private hospitals have started to pay attention to the personalization of the patients' rooms, they still do not allow patients to make major changes to the layout or decor. It is difficult for patients to feel safe and at home in an environment over which they have little or no control (Fig.11). From Rapoport's perspective, people need to bring objects, especially movable objects, to participate and bring meaning to their environments and increasing their sense of belonging (Rapoport, 1990a). Accordingly, patients staying in the hospital will have a reduced sense of belonging than a person monitored and treated at home due to the limited flexibility and control to the physical environment in a hospital. The patient's psychological conditions might be affected as well.

---

[4] Based on Galen Cranz's theory of taste, ***Taste= (Pragmatics + Symbols) Integrated Aesthetically*** (Galen Cranz, "A New Way of Thinking about Taste," *The Nature of Craft and the Penland Experience* (Lark, NY, 2004), pp. 130-136.)

Fig. 11 Interior of a patient room at Virginia Hospital Center , VA, USA (Virginia Hospital Center, 2013)

B. The Nursing Home

When patients' symptoms are not urgent enough to require hospitalization but still require regular medical assistance, they wind up at a nursing home. In the nursing home, patients live together in the same building, sharing several caretakers and a limited number of medical professionals. Each patient shares the same public living space, e.g. living rooms, dining rooms, etc., and may or may not have an individual space. Because residents do not have as many urgent medical demands, the nursing home requires fewer pragmatic objects than a hospital but more medical services than a home care environment. Since these residents are not as close as a real family but share the same living space, they cannot decorate the public space with individual symbolic objects as they please. For instance, it might cause unexpected conflicts to have two religious statues, coming from different religions, displayed simultaneously in the center the living room. All the users in the public space must approve the addition of such objects based on their personal tastes and comfort levels (Fig. 12).

Fig. 12 The interior of the living room in a nursing home (Karen Hanson, 2012)

C. Home Care

If a patient does not require intensive, immediate medical therapies, having caretakers in the home becomes an alternative. Patients could choose to stay at home, where their environment is most familiar and accessible. In addition to the positive psychological effects of maintaining independence, most pragmatic objects, e.g. medicine, toiletries, etc., are arranged according to the patient's taste, along with symbolic items. However, in long-term home care, if the caretaker stays and lives with the patient, the patient's personal taste will mingle with the caretaker's. Both the caretaker and the patient will be the main decision makers of the interior arrangement. Theoretically, from the relationship between employer and employee, the patient should have higher authority over the aesthetic assemblage in the interior (Fig. 13). Sometimes it depends on the patient's physical and psychological condition and how they interact with caretakers.

Fig. 13 The interior of the bedroom in home care (Mossaic Home Care Services, 2013)

D. Comparison

The issue of taste can be divided into four categories: pragmatic objects, symbolic objects, aesthetic formation[5], and the primary decision maker of the physical environment (Table 2). Generally, each medical institution prioritizes personal taste differently. Pragmatic items are closely related to the functionality of the institutions, and the emphasis on pragmatic and symbolic objects is the reverse of that in a home environment. A hospital or nursing home must make medical functionality the primary goal and thus the importance of symbolic objects decreases. Moreover, the entire aesthetic assemblage of the physical space is heavily related to the primary decision makers. Patients and the other users of the place are given various levels of authority in different medical institutions. Based on the results of these comparisons, home care service endows patients with more authority to maintain their own personal tastes than other more traditional health care services. Unless the level of hospital care service is required, most patients prefer to stay at home, having caregivers providing occasional or even daily assistance if necessary.

[5] According to Galen Cranz's theory of taste, ***Taste= (Pragmatics + Symbols) Integrated Aesthetically*** (Cranz, 2004)

	Pragmatic	Symbolic	Aesthetic	Core Decision Maker
Hospital	very strong	weak	Standardization	medical professionals
Nursing home	strong	normal	shared with other patients	multiple patients
Home care	normal	strong	personal expression	caretaker + patient

Table 2 The comparison of taste between three different health cares

3.4 Current Approaches

3.4.1 Barrier-Free Design/ Universal Design

In order to make built environments accessible and usable for the elderly and the physically disabled, the idea of barrier-free design began in the late 1950s. It proposes to remove barriers from the environment, enabling occupants to gain full access to the built environments, by allowing use of certain facilities, equipment, or products (Steinfeld, 1975). Barrier-free design conveys an interdisciplinary approach to problem-solving by focusing on the user of environments and demonstrating how all aspects of the physical environment have an effect on human behavior (Steinfeld, 1975, 1979). The scope of barrier-free design covers building, building products, landscape, transportation vehicles, and consumer products. Environmental barriers are found in several attributes of the physical environments, such the ontology of objects (e.g. size and location), the method of manipulating facilities, identification of information in the environment, etc.

As barrier-free design originally is perceived as a feature prescribed majorly for disabled people or the elderly, in Europe and Japan, barrier-free design has been explained more widely and developed into another term: universal design. Universal design, also called "life span design" or "inclusive design", is a term that was first used in the United States by Ron Mace in 1985. Universal design aims a holistic and integrated approach to design, ranging in scale from product design to architecture, and urban design on one hand, and systems controlling the ambient environment and information technology, on the other (Preiser & Ostroff, 2001). Universal design has multiple definitions and criteria worldwide (Story et al., 1998). The Center for Universal Design at North Carolina State University defines universal design as "the design of all products and environments to be usable by people of all ages and abilities, to the greatest extent possible."

However, there are some drawbacks in barrier-free design and universal design:

First, some design criteria contradict each other, or are hard to accomplish simultaneously. For instance, an interior allowing a wheel chair to pass unencumbered requires wider clearance than normal. However, to reduce the risk of falling, design guidelines call for an interior with objects that a falling person can grab and prevent injury (Satariano, 2006). A static interior cannot be both wide and narrow at the same time.

Further, barrier-free/ universal design seeks a general solution for the majority but neglects the value of uniqueness of individuals, including personal preference. To solve conflicts, barrier-free/ universal design must arrive at a consensus between the competing needs of multiple users (Pondy, 1967). It may provide an "acceptable" solution for multiple users, but not the most "appropriate" one to individuals.

Additionally, a solution provided by barrier-free/ universal design is fixed and unable to respond to changing needs of the user.

Finally, eliminating too many environmental barriers can also reduce chances for physical activity necessary to maintain the human body in good health. According to best gerontological practices, a certain degree of environmental challenges are needed in order to keep the human body trained and exercised (Lawton & Nahemow, 1973; Satariano, 2006)

In summary, the built environments proposed by barrier-free design and universal design are still too passive to respond to the changing bodily conditions of the occupants. Barrier-free design aims at assisting the elderly and the physically disabled by removing obstacles from built environments. Yet the physical environment without any obstacles may lead to insufficient chances for the occupants to exercise. Universal design seeks an integrated solution, making built environments usable by the people of all ages, abilities, and genders. However, in home care service, each patient is unique and has different physical /psychological conditions that should be respected. A generalized, static design solution is hardly capable of fulfilling all individual requirements.

After the digital revolution of the 1990s, new technologies brought huge impacts to human civilization, including the health care industry. The following sections will review two applications of health care technologies: 1) patient-centered assistant technologies and 2) monitoring system: E-health.

3.4.2 Patient-centered Assistant Technologies

The use of patient-centered assistant technical facilities, e.g. remote monitoring and diagnostic systems, has partially expanded professional medical assistance into patients' residential environments. Patients could, for example, be monitored and notified of bodily conditions while utilizing remote medical facilities at home.

The Health Systems Institute at the Georgia Institute of Technology is an interdisciplinary organization that aims to address several health care issues, e.g. health resources, health outcomes and quality, human factors/human-computer interaction, health decisions and risk analysis, e.g. Dynamic Pupil Behavior and Comprehensive IT Solution for Quality and Patient Safety. Some of these research paths illustrate specific technologies or facilities according to particular topics, while others engage in information systems of communication and database analysis. Nevertheless, the environments using these technologies are still passively reactive. These advanced technical systems cannot function until the facilities are manipulated correctly. However, patients might have difficulty utilizing these facilities at home, especially during an emergency. A cardiac event, for example, could obviously become a life-threatening situation and could raise other lesser health issues if not correctly assessed.

To overcome these drawbacks, the home health care environment requires a holistic, intelligent system capable of organizing and managing these various ad-hoc technologies together. Ideally, an intelligent home health care system should make built environments smart enough to respond actively to patients' activities.

3.4.3 Monitoring System: E-Health

In response to the growing population, more and more countries are developing home healthcare practices supported by electronic equipment and processes (E-Health). One of the current research institutions is the Center for Aging Services Technologies (CAST), organized by Intel Proactive Research and academic organizations. Intel and university researchers utilize wireless sensor networks, combined with computing and complex algorithms to assist the elderly.

The research project "Making Eldercare Easier" shows a smart home system that detects, monitors, and records the daily living activities of a senior citizen by collecting data through postage stamp-sized wireless Radio Frequency Identification (RFID) tags affixed to household objects. Ultimately, the system could help manage everyday activities so that seniors' independence is maintained while relieving some of the burdens placed on around-the-clock caregivers.

Nevertheless, this research lacks discussion of the cause-and-effect between activities and demands. Occupants may want to achieve the same goal but have different behaviors. Instead, the system should track daily activities, and analyze the sequence between these activities in terms of social/ cultural backgrounds of the user. Consequently, the system can even propose more efficient or appropriate solutions to meet the user's daily demands.

3.5 Conclusion

This chapter probes into issues of home care environments from several perspectives: 1) epidemiology of aging, 2) comparisons of health care services among different medical institutions, and 3) current approaches of home care services. If the patients' physical condition doesn't require hospital-level medical assistance, most patients prefer to choose home care service over being treated in a hospital or nursing home, as home care service enables the patient to make their own decisions, supporting their personal preferences and taste. The current approaches of home care services are either too generalized (e.g. universal design) or too passive to interact with the ever-changing demands of the elderly. Consequently, the home care environment requires a holistic, intelligent system capable of organizing and managing various ad-hoc technologies together, smart enough to respond to patients' activities. After reviewing background knowledge regarding intelligent environments and home care service in chapter two and chapter three, the next part of this research will develop research hypotheses as well as research methods.

PART II

Developing Research Methods

Part II elaborates research strategy by two chapters. Chapter IV is initiated from research hypotheses and followed by the development of research methods: 1) the on-site case study in home care, 2) system development of intelligent home care environments, and 3) system testing and evaluation. Chapter V develops user profiles and identifies representative samples of health issues for system testing with scenarios.

Chapter IV

Hypotheses and Research Methods

This chapter defines research hypotheses and elaborates on research methods. Research methods comprise 1) case studies and literature review, 2) dynamic multi-agent system design, 3) human-environmental design, and 4) system testing and evaluation.

4.1 Research Hypotheses

This section develops research hypotheses based on several underlying premises from three perspectives: 1) human-environmental interaction, 2) home care services, and 3) multi-agent system design. The first premise is that the responsiveness of the built environments to ever-changing human needs can be improved by making them "intelligent," that is – "aware" of their context and content, and able to change their configuration or otherwise respond to external and internal changes (Minker, Weber, & Hagras, 2009). This requires new thinking and proceeds to develop a new interactive model of such an intelligent environment for home care of the elderly. It is of particular use in home care for elderly people, because intelligent environments could be made responsive to the needs of the elderly by assisting their physical and cognitive functioning. Accordingly, the second premise is that the proposed Intelligent Home Care Environment (IHCE) could assume, or share the workload traditionally fulfilled by human caretakers (Harris, 1994), and therefore decrease potential conflicts between the elderly and their caregivers. Meanwhile, IHCE can intervene / delay the disablement process (Verbrugge & Jette, 1994) of the elderly by assisting with successful rehabilitation.

While responsive, so-called "intelligent" environments have been proposed by others (Mozer, 1998; Negroponte, 1970, 1975; Sakamura, 1996), they were based on a feedback model, where the environment responded to changes initiated by the occupants. The proposed intelligent environment, in contrast, will be able to interact with and respond to the occupants' need on a case-by-case basis, and also have the ability to initiate actions on its own, based on a holistic model of the human/environment. It could thus optimize safety[6], resource efficiency[7], and adaptability[8] by avoiding problems, not only solving them.

To accomplish this task, the intelligent environment will be designed by using intelligent agents (Minsky, 1988; Padgham & Winikoff, 2004; Weiss, 2000; Wooldridge, 2002) – software that mimics the behavior of self-initiating humans. To provide the holistic view, Acupuncture Theory will be used as a metaphor to design an overall schema for the intelligent multi-agent system. The third premise is that by applying Acupuncture Theory as a metaphor, the intelligent multi-agent system could be endowed with the ability to propose optimized solutions among safety, resource efficiency, and adaptability.

Inducted from the aforementioned premises, the research hypotheses are as follows: this research proposes Intelligent Home Care Environment (IHCE) as a solution that can assist the elderly with physical and cognitive functioning, while reducing costs and avoiding the social and cultural problems associated with current solutions. By applying Acupuncture Theory as a metaphor for designing intelligent multi-agent systems, the proposed IHCE is able to assist the elderly through the optimization among safety, adaptability, and resource efficiency. With the assistance of IHCE, the elderly may live more independently longer, have higher self-confidence, and enjoy a successful (Rowe & Kahn, 1997), well-balanced, and healthy aging.

4.2 Research Methods

In order to examine the actual needs to which the IHCE needs to respond, and to develop design criteria for the IHCE, this study reviews qualitative and quantitative studies in human-environment interaction in home care that describe how home care is affected by interactions between the elderly and their caretakers. Three types of studies are included: 1) an on-site case study focusing on one patient with four caregivers, 2) Cross-Cultural and Ethical Variation Study in Home Care from reviews of the literature , and 3) The Healthy Aging Network Walking Study in which data were collected from 884 subjects located in four distinct areas of U.S. The first two studies (on-site case study and the literature review) contribute to formulating a knowledge base of user profiles in the system. The third study is based on a quantitative case study that covers hundreds of subjects, helping define representative samples for system testing and evaluation.

Based on these studies, a design prototype of IHCE is developed before the system is constructed physically. The ability of the prototyped IHCE to meet its design criteria will be tested through various scenarios (a physical system will not be constructed at this stage in the research due to cost, time, and other constraints). In summary, this research comprises three

[6] Safety represents the maintenance of the user's health and well-being. The standards of Safety Agent should be customized according to the user's personal status, e.g. the user's history of present illness (HPI). It also should be flexible and responsive to the changes of the user's physical and cognitive function.

[7] Resource efficiency involves budgeting both the construction and maintenance of an entire intelligent environment system. Regarding sustainability, natural resources are precious and limited as well. An intelligent environment for home care is expected to help the patient effectively and run efficiently enough to conserve natural resources.

[8] Adaptability is defined as the usability and appropriateness that an environment could provide to support multiple, dynamic activities based on the user's social/ cultural background, e.g. personal and cultural taste. An ideal intelligent environment in home care should be able to adjust on its' own, helping users function in the physical environment appropriately, and increasing users' comfort and convenience both physically and psychologically.

phases: 1) qualitative/quantitative studies in home care, 2) the prototype development of IHCE, and 3) scenario testing and evaluation.

4.2.1 The On-Site Case Study in Home Care

The on-site case study will be held for two purposes: 1) to research the interaction between the caretaker and the elderly in home care, and 2) to research how the patient's physical and cognitive functioning could be affected by home care services.

A. The Target Audience of this research:

The main subjects of this research should meet basic qualifications as follows:

- The target audience in this research are elderly people capable of behaving independently or semi-independently (approximately between 65~85 years old).
- The patient has clear self-awareness and the ability to recognize, plan, and achieve goals in daily life.
- The patient needs some level of health care services, but not requiring continuous hospital-level medical assistance.

B. Data Collection

To research social/ cultural influence in home care, by expanding Cranz's Theory of Taste[9], the on-site case study focuses on how the patient's cognitive functions could be affected regarding the home care services and supportability of the patient's taste.

C. Home Care Service Evaluation

The case study intends to research how different caregivers interact with single patients, and how diversities of the caretaker's social/ cultural backgrounds affect their interaction with the patient. This case study focuses on the interrelationship between a single patient and multiple caretakers over a certain period. Each caretaker must assist the patient at least 8 hours a day continuously for more than one year.

Data collection techniques include direct/ indirect observation, structured interviews, and photo analyses of indoor environments. Structured interviews aim at different levels of satisfaction from two perspectives: the evaluation of 1) the quality of home care services and 2) support of the patient's personal and cultural taste. In terms of home care service measures, four service categories are evaluated: food, dressing, bathing, and medication[10]. Each service includes several subcategories and an overall evaluation (KMG Monks, 2000; Springhouse Corporation, 2001).

---

[9] ***Taste= (Pragmatics + Symbols) Integrated Aesthetically*** (Galen Cranz, "A New Way of Thinking about Taste," *The Nature of Craft and the Penland Experience* (Lark, NY, 2004), pp. 130-136).

[10] The official guideline is provided by the U.S. Department of Health and Human Services. It mainly focuses on the evaluation of pragmatic medical services, e.g. the assistance of the patient's locomotion. This guideline relates more to the patient's physical activities instead of taste.

D. Supportability of the Patient’s Taste

Each caretaker will be evaluated on how they support the patient’s taste in the physical environment. The evaluation will be processed in terms of pragmatic objects, symbolic objects, and aesthetic integration based on the patient’s degrees of satisfaction.

E. Photo Analyses

Photo analyses will explore how indoor physical environments are arranged differently before and after the caregiver start assisting the patient in terms of pragmatic and symbolic objects according to the caretaker’s aesthetic viewpoints.

4.2.2 System Development of Intelligent Home Care Environments

Endowing the physical environment with artificial intelligence requires mediators to assist in the interaction between that environment and users. Intelligent environments generally require a so-called “intelligent agent” (IA) to act as an interface enabling the intelligent environment to provide more flexibility and adaptability to the user according to ever-changing activities.

A. Dynamic Multi-Agent System Design

In thinking of intelligent-built environments as living ecology, Acupuncture Theory is employed as a metaphor that elaborates a holistic, systematic viewpoint of the human body for energy optimization (Ming-Tung Chen, 2000; Zhang & Rose, 2001). It comprises numerous acupuncture points functioning, cooperating, and managed in terms of multiple subsystems, e.g. energy channels, five phases, and biological systems (e.g. the immune system and the digestive system) (Deadman, Al-Khafaji, & Baker, 2007; Ming-Tung Chen, 2000). Acupuncture Theory contains several characteristics such as 1) a dynamic hierarchy and 2) dynamic grouping/ control scope that can be applied as a model to formulate Dynamic Multi- Agent System (DMAS) for the proposed intelligent environment.

In order to provide flexibility for optimizing the environment, IHCE will be composed of Dynamic Multi-Agent Structure (DMAS) with distributed IAs. The DMAS is structured in a dynamic hierarchy and comprises three types of IAs from top to bottom in sequence: Environmental Optimization Agents (EOA), Scheme Management Agents (SMA), and Object Agents (OA) (Fig. 14).

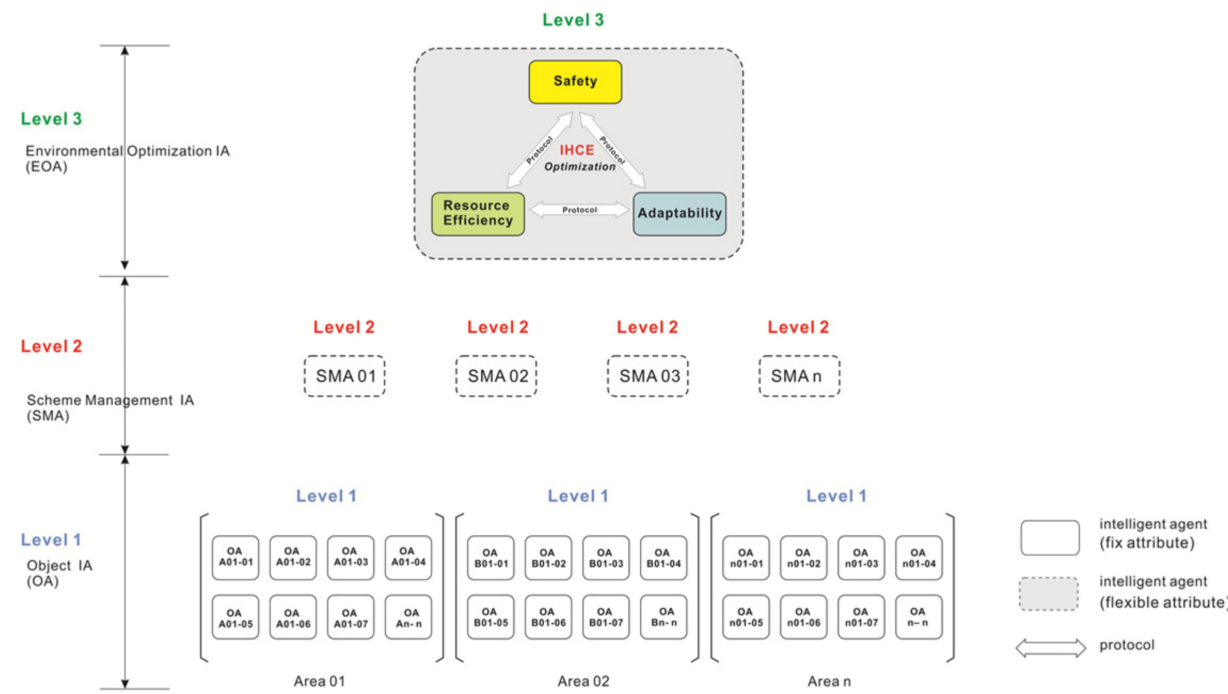


Fig. 14 The diagram of Intelligent Home Care Environment (IHCE)

B. Human-Environmental Interface Design

To enable the physical environment to be flexible enough to respond to a user's ever-changing demands, IHCE contains many smart appliances, allowing the user to interact with the intelligent environment. In considering that the target audience of this research is the elderly, it is essential to construct human-environmental interfaces that set entirely new standards of user friendliness; it must be both easy to understand and to interact intuitively. This research integrates several disciplines as design criteria for human-environmental interface design, including the epidemiology of aging, sociology, social/ cultural factors, body-mind consciousness, and human-computer interaction. More details will be reviewed in *Section 6.3.2, "Theories of Human-Environmental Interaction*."

4.2.3 System Testing and Evaluation for External Validity

Since constructing the proposed intelligent environment in reality requires abundant financial and human resources, this research formulates a hypothetical prototype of IHCEs for surrogate empirical system testing and evaluation, prior to physical construction. The scenarios are derived from empirical studies of common health problems, aiming to examine the proposed IHCE from three perspectives: 1) the ability to propose optimized assistance in home care, 2) the ability to assist the elderly with physical and cognitive functioning, re-actively and proactively, and 3) the ability to assist the elderly while respecting their personal taste.

To examine how the proposed IHCE can apply to the majority of the target audience regarding external validity, this research applies database of Healthy Aging Network Study (HANS), associating with 886 subjects in four different areas in the U.S. (William A. Satariano et al., 2010), to define representative sample types for testing. Each sample type represents certain amount of the subjects that contains a set of variables regarding physical or cognitive functioning. The list of scenarios and objectives for examining IHCE is illustrated as follows (Table 3):

Scenario Objective	Scenario Number	IHCE Assistance
Reactive/ Proactive assistance in Activities of Daily Living (ADL)/ Instrumental Activities of Daily Living (IADL)	Scenario 01	▪ Dressing ▪ Housework (Laundry) ▪ Bathing/ Showering
	Scenario 02	▪ Meal Preparation ▪ Physical functioning (has trouble of stooping, crouching or kneeling)
Safety Issues (Code Blue)	Scenario 03	▪ Medication ▪ Fall Monitoring
	Scenario 04	▪ Suspicious Events Monitoring
Multiple Activity Scenario Evaluation	Scenario 05	▪ Nyctalopia (night blindness) ▪ Has trouble of getting up from a deep bend, crouching or kneeling position ▪ Traveling ▪ Financial management ▪ Shopping ▪ Depression ▪ Medication ▪ Social Network ▪ Health monitoring (sitting posture)

Table 3 The objectives and IHCE assistance of scenarios

To evaluate the proposed IHCE system, five categories of design criteria are inducted based on the hypotheses addressed in *Section 4.1*. Accordingly, design criteria for system evaluation are proposed as follows (Table 4):

Number	1	2	3	4	5
Category	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
Criteria	• ADL • IADL	• Sense of Control • Sense of Coherence • Self-Efficacy	• Safety • Resource Efficiency • Adaptability	• Reactive • Proactive • Social • Autonomous • Flexible	• Pragmatic • Symbolic • Aesthetic

Table 4 The list of design criteria for the system evaluation

Derived from gerontology, the first two criteria reviews the home care assistance in terms of the physical and cognitive functioning of the elderly. The first criterion identifies home care assistance regarding the elderly's physical functioning categorized as Activity of Daily Living (ADL) and Instrumental Activity of Daily Living (IADL)[11]. The second criterion reviews how the elderly's cognitive functioning is assisted in three areas: sense of control, sense of coherence, and self-efficacy[12].

The third criterion examines the ability of IHCEs to propose optimized home care assistance. By applying acupuncture theory as a metaphor for designing multi-agent systems, the proposed IHCE is able to provide holistic home care assistance focused on three key system goals: safety, resource efficiency, and adaptability. The forth criterion applies theories in intelligent environments to review the functionality of multi-agent systems. To consider the system being intelligent, five capabilities are reviewed as follows: re-active, proactive, social, autonomous, and flexible. More details regarding the fourth criterion is documented in *Section 2.3.1, "When can an agent be considered 'intelligent?"*

The former four criteria mainly focus on reviewing the functionality of home care service, while the fifth criterion applies Cranz's Taste Theory to evaluate home care service in terms of service quality. As discussed in *Section 3.2, "Why people choose home care"*, one reason that patients tend to prefer home care service is because home care environments support personal taste better than any other medical organizations, e.g. hospitals or nursing homes. Thus, the fifth criterion not only examines the functionality of home care service, but also reviews how the patient's personal taste is respected.

4.3 Conclusion

This chapter develops research hypotheses based on the underlying premises from different perspectives: 1) proposing Intelligent Home Care Environments (IHCEs) as a solution that can assist the elderly regarding their physical and cognitive functioning, and 2) by applying Acupuncture Theory as a metaphor for designing intelligent multi-agent systems, the proposed IHCE is able to assist the elderly through the optimization among safety, adaptability, and resource efficiency. To proceed with this research, three types of studies are applied: 1) one on-site case study focusing on one patient with four caregivers, 2) Cross-Cultural and Ethical Variation Study in Home Care from reviews of the literature, and 3) The Healthy Aging Network Walking Study in which data were collected from 884 subjects located in four distinct areas of the U.S. The first two studies (on-site case study and literature review) contribute to formulating a knowledge base of user profiles in the system, while the third study helps define representative samples for system testing. Since constructing the proposed intelligent environment physically requires abundant financial and human resources, this research proposes a theoretical model of IHCEs for surrogate empirical system testing and evaluation, prior to physically constructing it. The scenarios are derived from empirical studies of common health problems. To evaluate the

[11] In gerontology, physical functioning can be measured in terms of Activities of Daily Living (ADL) (Katz et al., 1963) and Instrumental Activities Daily Living (IADL)(Lawton & Brody, 1969). Please refer to *Section 1.2.2* for details of ADL and IADL.

[12] Cognitive functioning refers to the psychological issues involved in home care services. In gerontology, cognitive functioning could be discussed in three areas: sense of control, sense of coherence, and self-efficacy. Please refer to *Section 1.2.2* for the definition of cognitive functioning in details.

proposed IHCE, five categories of design criteria are developed from the following disciplines: gerontology, intelligent environments, intelligent agents, and social/ cultural perspectives. The next chapter delineates how these studies contribute to developing user profiles and identifying representative samples for system testing.

Chapter V

Developing User Profiles for Intelligent Home Care Environments and Identifying Representative Types of Health Issues

This chapter outlines several research studies from three distinct sources: 1) an on-site case study, 2) reviews of the literature regarding cross-cultural and ethical variation studies in home care, and 3) the development of representative sample derived from the Healthy Aging Network Walking Study (HANS), including the subject's characteristics and challenges as well as the types and degrees of assistance required (William A. Satariano et al., 2010). The first two sources (the on-site case study and the literature review) contribute to formulating the knowledge base regarding the user's profile in the intelligent system, while the third study (HANS) helps identify representative samples with critical health issues for system testing and evaluation regarding external validity of the research.

5.1 On-site Case Study

Home care provides greater flexibility, outcomes and accessibility for patients compared with health care services provided by hospitals and nursing homes. By expanding Prof. Cranz's theory[13] of taste, the case study focuses on how the patient's cognitive function could be affected regarding the home care services and supportability of the patient's taste and preferences. This qualitative research focuses on the interrelationship between one patient (Table 5) and four international caretakers (Table 6) over ten years. Each caretaker lives with the patient in the same room for two to three years.

	Patient 01
Citizenship	Taiwan
Race	Asian
Age	99
Educational Level	Primary school
Religion	Taoism
Gender	Female
Length of home care	10 years

Table 5 The patient profile

[13] ***Taste= (Pragmatics + Symbols) Integrated Aesthetically*** (Galen Cranz, "A New Way of Thinking about Taste," *The Nature of Craft and the Penland Experience* (Lark, NY, 2004), pp. 130-136.)

	Caretaker 01	Caretaker 02	Caretaker 03	Caretaker 04
Citizenship	the Philippines	Indonesia	Vietnam	Indonesia
Race	Asian	Asian	Asian	Asian
Age	31	27	40	21
Educational Level	University	High school	Primary school	Primary school
Religion	Christianity	Islam	Buddhism	Islam
Gender	female	female	Female	female
Length of service	2 years	3 years	2.5 years	2.5 years

Table 6 The profile of four caretakers

5.1.1 Data Collection

Data collection techniques include observation, phone interviews, and photo analysis (Fig. 15). Phone interviews focused on different levels of satisfaction from two perspectives: the evaluation of 1) the quality of home care service and 2) support of the patient's personal and cultural taste. In terms of home care service measures, four service categories are evaluated: food, dressing, bathing, and medication[14]. Each service includes several subcategories and an overall evaluation (Table 7-10).

1) The Quality of Home Care Service

- **Food Service**

		very unsatisfied			neutral			very satisfied
		0	1	2	3	4	5	6
Pragmatic	Feeding skill	□	□	□	□	□	□	□
Flavor	Food freshness	□	□	□	□	□	□	□
Symbolic	Cultural appropriateness	□	□	□	□	□	□	□
Aesthetic	Appearance	□	□	□	□	□	□	□
Overall service		□	□	□	□	□	□	□

Table 7 The evaluation of food service

- **Dressing Service**

		very unsatisfied			neutral			very satisfied
		0	1	2	3	4	5	6
Pragmatic	Cleanliness	□	□	□	□	□	□	□
	Warmth	□	□	□	□	□	□	□
Symbolic	Social appropriateness	□	□	□	□	□	□	□
Aesthetic	Style	□	□	□	□	□	□	□

[14] The official guideline is provided by the U.S. Department of Health and Human Services. It mainly focuses on the evaluation of pragmatic medical services, e.g. the assistance of the patient's locomotion. This guideline relates more to the patient's physical activities instead of taste.

	Color	☐	☐	☐	☐	☐	☐	☐
Overall service		☐	☐	☐	☐	☐	☐	☐

Table 8 The evaluation of dressing service

- **Bathing Service**

		very						very
		unsatisfied			neutral			satisfied
		0	1	2	3	4	5	6
Pragmatic	Cleanliness	☐	☐	☐	☐	☐	☐	☐
	Bathing skill	☐	☐	☐	☐	☐	☐	☐
Symbolic	Toiletries	☐	☐	☐	☐	☐	☐	☐
Aesthetic	Toiletry arrangement	☐	☐	☐	☐	☐	☐	☐
Overall service		☐	☐	☐	☐	☐	☐	☐

Table 9 The evaluation of bathing service

- **Medication Service**

	very						very
	unsatisfied			neutral			satisfied
	rare			neutral			frequent
	0	1	2	3	4	5	6
Accuracy of dosages	☐	☐	☐	☐	☐	☐	☐
Frequency of demands for unplanned medical care	☐	☐	☐	☐	☐	☐	☐
Frequency of new wound or infection needed for extra medical care	☐	☐	☐	☐	☐	☐	☐
Overall service	☐	☐	☐	☐	☐	☐	☐

Table 10 The evaluation of medication services

2) Support of The Patient's Personal and Cultural Taste

Each caretaker has been evaluated on how they support the patient's taste in the physical environment. The evaluation form will be processed in terms of pragmatic objects, symbolic objects, and aesthetic integration based on the patient's degrees of satisfaction. (Table 11-13)

- **Pragmatic objects**

	unsatisfied			neutral			satisfied
	0	1	2	3	4	5	6
Medical objects	☐	☐	☐	☐	☐	☐	☐
Dressing	☐	☐	☐	☐	☐	☐	☐
Food	☐	☐	☐	☐	☐	☐	☐
Bathing	☐	☐	☐	☐	☐	☐	☐
Others	☐	☐	☐	☐	☐	☐	☐
Overall supportability	☐	☐	☐	☐	☐	☐	☐

Table 11 The supportability of pragmatic objects

- **Symbolic objects**

	unsatisfied			neutral			satisfied
	0	1	2	3	4	5	6
Religious objects	☐	☐	☐	☐	☐	☐	☐
Family photos	☐	☐	☐	☐	☐	☐	☐
Collectables	☐	☐	☐	☐	☐	☐	☐
Paintings	☐	☐	☐	☐	☐	☐	☐
Souvenirs	☐	☐	☐	☐	☐	☐	☐
Others	☐	☐	☐	☐	☐	☐	☐
Overall supportability	☐	☐	☐	☐	☐	☐	☐

Table 12 The supportability of symbolic objects

- **Aesthetic assemblage**

	unsatisfied			neutral			satisfied
	0	1	2	3	4	5	6
Object arrangement	☐	☐	☐	☐	☐	☐	☐
Shape integration	☐	☐	☐	☐	☐	☐	☐
Texture integration	☐	☐	☐	☐	☐	☐	☐
Pattern integration	☐	☐	☐	☐	☐	☐	☐
Scale arrangement	☐	☐	☐	☐	☐	☐	☐
Symmetrical arrangement	☐	☐	☐	☐	☐	☐	☐
Diagonal arrangement	☐	☐	☐	☐	☐	☐	☐
Others	☐	☐	☐	☐	☐	☐	☐
Overall supportability	☐	☐	☐	☐	☐	☐	☐

Table 13 The supportability of aesthetic assemblage

5.1.2 Photo Analyses

Taste Analyses of the Interior - Caretaker 01

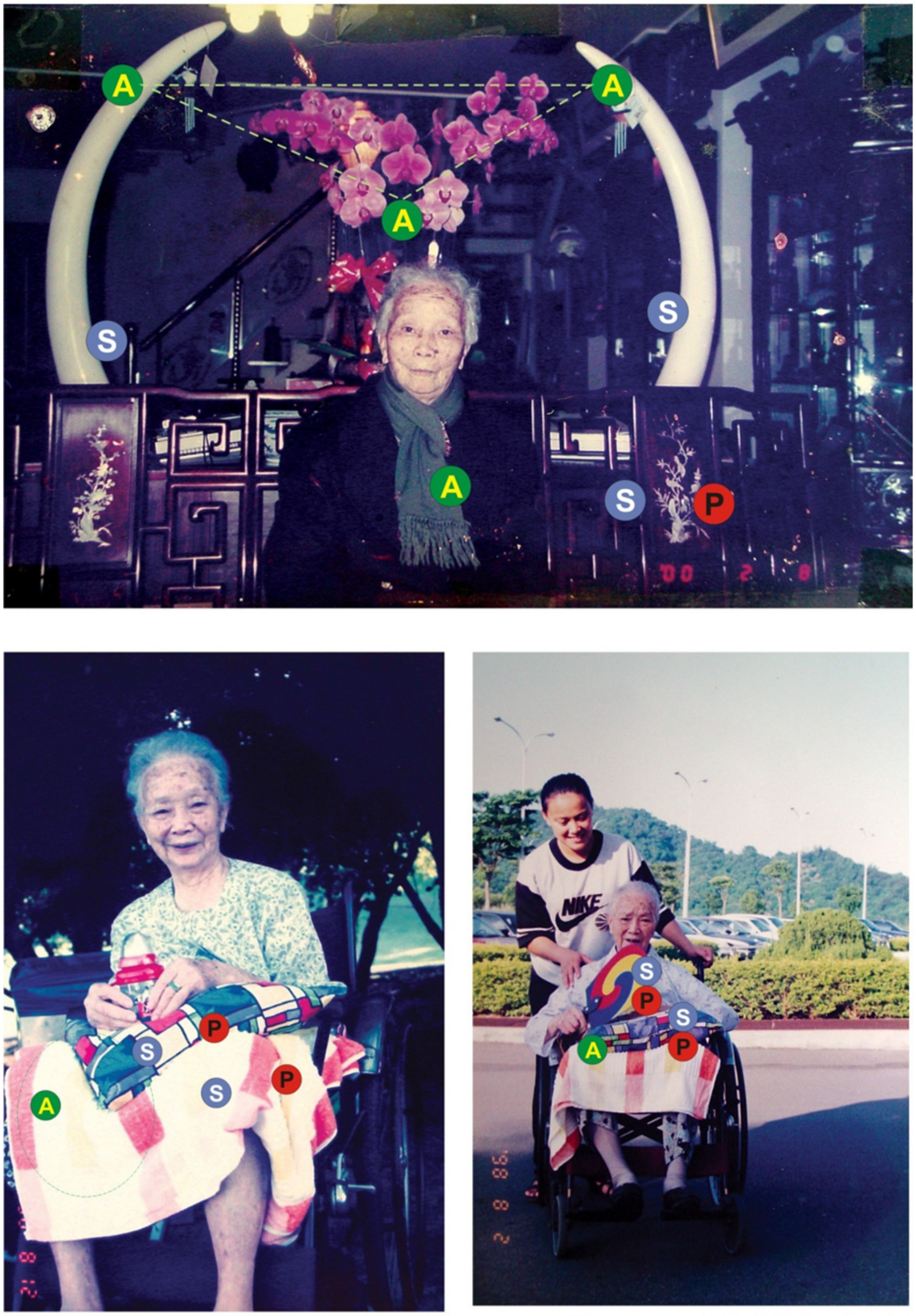


Fig. 15 Taste Analysis of the Interior- Caretaker 01

5.1.3 Finding

A. Home Care Service Quality

Caretakers 01 and 03 have the highest rated performances (Fig. 16). One explanation for this difference might be that Caretaker 01 has the highest education level, while Caretaker 03 is the oldest and therefore the most experienced. Nevertheless, Caretaker 01 scored more evenly among the four different home care services than Caretaker 03. In comparison of caretakers 02 and 04, Caretaker 02 performed better, which might be due to a higher education level as well. In terms of personal service strength, Caretaker 01 performed the best in dressing services. Meanwhile, Caretaker 03 satisfied the patient best in medication and bathing services.

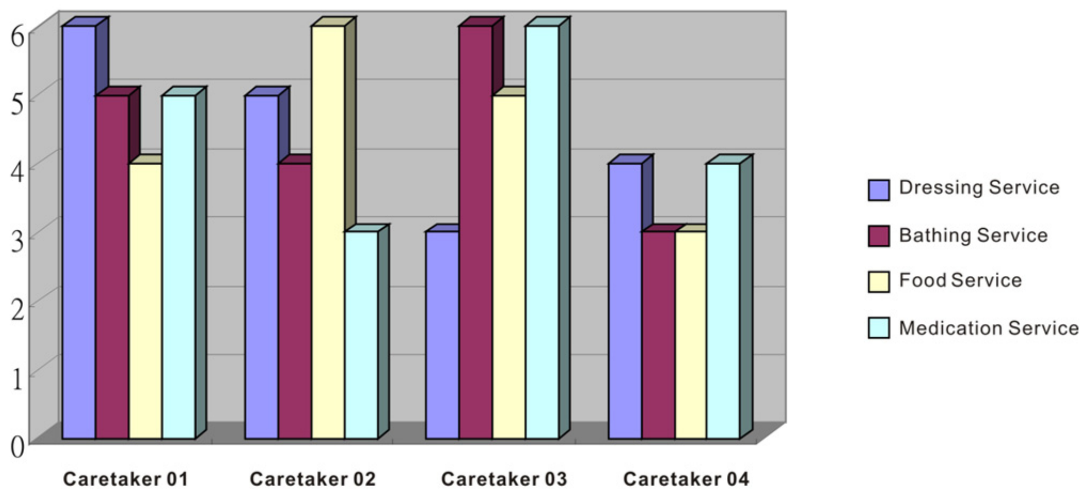


Fig. 16 Comparison of Home Care Service Quality between caretakers 01-04

Figure 17 shows quantities of home care service in terms of area of quadrangles as well as distinct service qualities in different shapes. Caretakers with different social/cultural backgrounds have different performance outcomes in home care service evaluations. In the area representing the overall quality of services Caretaker 03 is the oldest, and also happens to rate better than the youngest caretaker (Caretaker 04). Nevertheless, Caretaker 01, who also has the highest education level, performs better than the oldest and presumably most experienced (Caretaker 03).

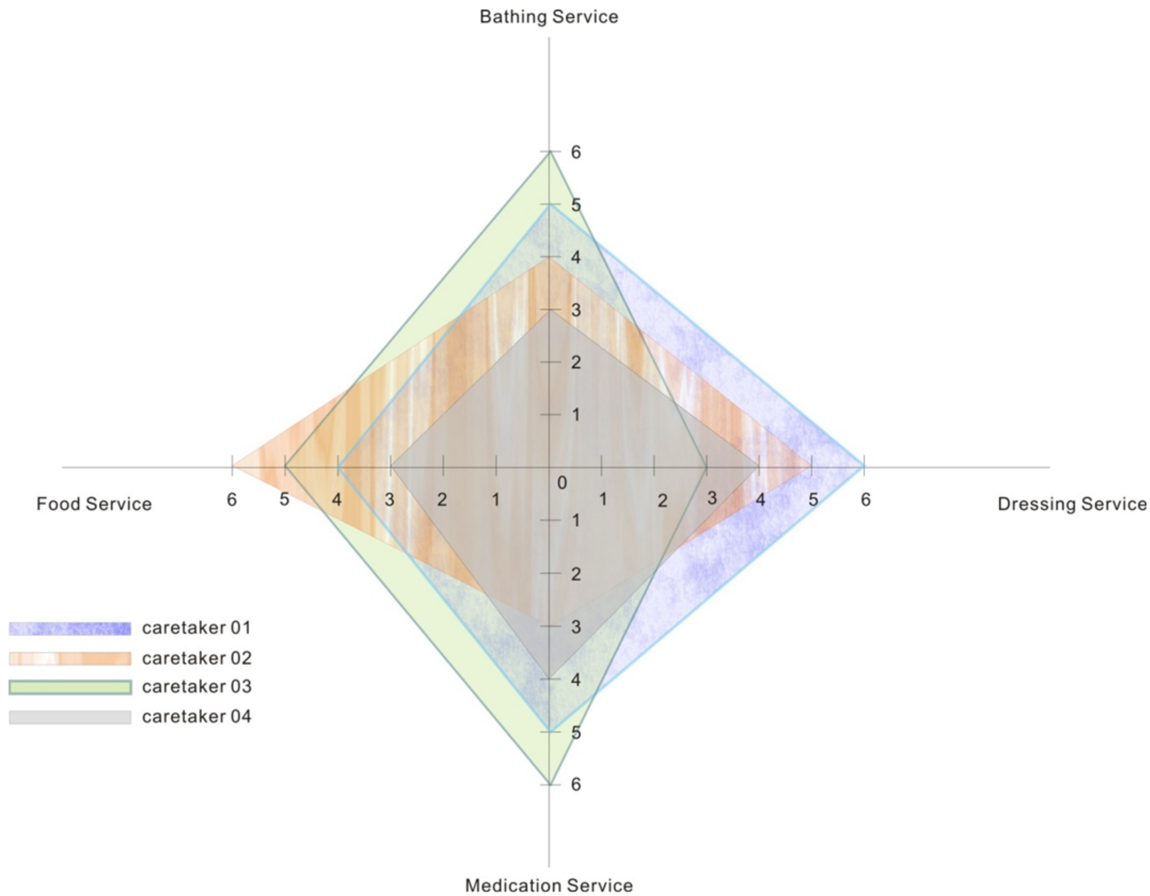


Fig. 17 Home Care Service Quality (Patient's Level of Satisfaction)

B. Supportability of the Patient's Taste

When examining how each caretaker supports the patient's taste (Fig. 18), there is little difference among pragmatic services, symbolic services and aesthetic assemblage. Caretaker 01 rated relatively higher in aesthetic assemblage. Caretaker 03, the oldest caretaker, better supports the patient's taste in pragmatic services. Caretaker 02 is more familiar with utilizing symbolic items to support the patient's taste. Caretaker 04 seems to satisfy the patient's taste less except in functional pragmatic services.

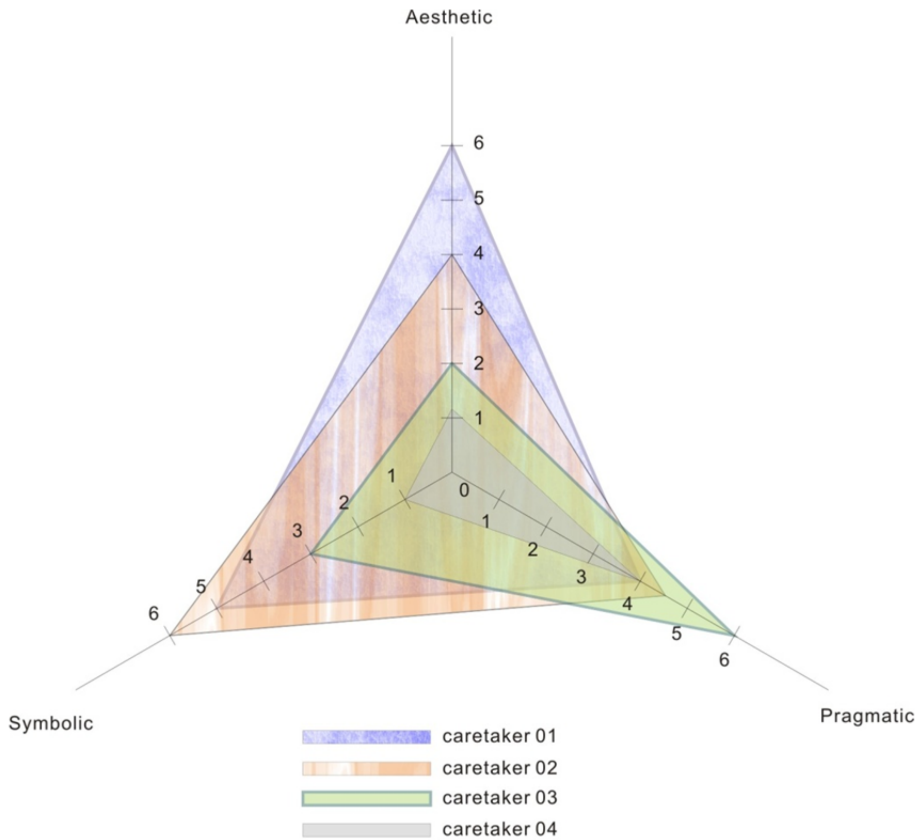


Fig. 18 Supportability of The Patient's Taste (Based on the Patients' Satisfaction)

In general, the oldest caretaker pays more attention to pragmatic service while the youngest one pays the most attention to symbolic objects. The caretaker with the most education received the best evaluations in all areas.

C. Other Information from the Interview

According to the interview, each international caretaker is under contract to work for a limited period of around two and a half to three years. Consequently, the patient must adapt to and explain personal preferences to new caretakers every few years. This repetition makes the patient feel frustrated, especially as she gets older.

The patient also mentioned why she felt disappointed with Caretaker 04 but complained less to her. As the patient aged, she had less energy to argue with the caretaker when conflicts occurred, especially over issues that did not concern pragmatic objects. For instance, each time the family pictures fell off the wall, the patient grew tired of asking Caretaker 04 to put them back in their original arrangement.

5.1.4 The Home Care Service Profile

This case study in home care shows holistic factors by which patients consider, rate and are comfortable with how each caretaker provides nursing services, including pragmatic, symbolic, and aesthetic perspectives, not just one of them. Accordingly, the proposed IHCE should be able to assist the elderly based on how they evaluate home care services. To achieve this goal, the criteria of questionnaires for home services are applied as variables to formulate a knowledge base about the user. It allows the user to input personal profiles that will be continually updated through system learning (Table 14).

Service Type	Evaluation Category	
Food Service	Pragmatic	Nutrition
		Food freshness
	Symbolic	Social appropriateness
		Cultural appropriateness
		Flavor
	Aesthetic	Appearance
	Others	
Dressing Service	Pragmatic	Cleanliness
		Warmth
	Symbolic	Social appropriateness
		Cultural appropriateness
	Aesthetic	Style
		Color
		Combination
	Others	
Bathing Service	Pragmatic	Cleanliness
		Water temperature
	Symbolic	Toiletries
		Fragrance of body cleaner (e.g. soap/ shampoo/ Lotion)
	Aesthetic	Toiletry arrangement
		Bathing style (e.g. shower/ hot tub/ with flowers)
	Others	
Medication Service	Pragmatic	Accuracy of dosages
		Accurate timing of dosages
	Symbolic	Medication type (western/ eastern medicine)
	Aesthetic	Personal preference after medication (e.g. amount of water/ water temperature/ having candy after medication)
	Others	

Table 14 The format of knowledge base for the home care service profile

5.1.5 The Personal Taste Profile

According to the case study, the user's psychological state is affected greatly by how their taste is respected in home care services. Thus, good home care services should not only take care of the patient's physical functioning, but also should assist the patient's cognitive functioning and be tailored to their personal taste based on various social and cultural backgrounds. To enable the proposed IHCE to adhere as closely as possible to the personal taste of the user while providing home care services, a taste evaluation form is applied to formulate personal taste profiles (Table 15).

Taste category	Variables
Pragmatic Objects	Medication
	Dressing
	Foods
	Bathing
	Others
Symbolic Objects	Religious objects
	Family photos
	Collectables
	Dressing
	Paintings
	Souvenirs
	Others
Aesthetic Assemblage	Service Sequence arrangement (e.g. prefer taking a shower after running)
	Object arrangement
	Shape integration
	Texture integration
	Pattern integration
	Scale arrangement
	Symmetrical arrangement
	Diagonal arrangement
	Others

Table 15 Personal taste profile

This one-site case study is qualitative research that aims at uncovering the depth of home care service among a single subject with four different care givers. The next case study aims at quantitative research data based on cross-national literature review to discuss cultural and ethnic variations of home care services.

5.2 Cross-Cultural and Ethical Variation Studies in Home Care

Patients whose cultural backgrounds differ from their caregivers frequently feel misunderstood, "out of sync," alienated, and in conflict with the healthcare provider (C.P. Germain, 1992; Leininger, 1991). This problem has been exacerbated by the fact that nurses used to be told to "treat all patients alike." Caring for patients at home requires much more than knowledge of disease processes. Accordingly, this study aims to discuss cultural and ethical variation in home care among different cultures and countries through literature review. The discussion is based on multiple case studies in Asia from several perspectives, including verbal and nonverbal communication, food services, psychological care, and folk treatments. A cultural evaluation form derived from this research contributes to constructing the knowledge base regarding the user's profile in the intelligent system (American Medical Association, 2001; Blank, 2007; Buhler-Wilkerson, 2001; Bumagin, 2001; Burau, 2007; C.P. Germain, 1992; Diamond, 1992; Francine Rainone & McHugh, 2007; French Jean & R, 1973; Galanti, 1991; Geri-Ann Galanti, 1999; Harris, 1994, 2005; Iezzoni, 2002; Jaffe, 1997; Lang, 2008; Leininger, 1991; Lipson Jg, 1985; Lipson, 1996; M.C. Narayan, 1997; Margaret M. Andrews & Boyle, 2011; Marie E. Cowart & Streib, 1987; Mercer, 1996; Mitty, 2005; KMG Monks, 2000; Karen Monks, 2002; S. Montauk, 1998; S. L. Montauk, 1998; Murashima, 2002; Prieto, 2008; Springhouse Corporation, 2001).

5.2.1 Cross-Cultural and Ethical Variation Comparison

Cultural differences, both small and large, exist in home health care. Although no two cultures are exactly the same, most eastern and western cultures have similarities. These cultural similarities may be due to ethnicity, geographic regions, etc. For instance, Taiwanese and Japanese cultures have much in common because they come from the same origin thousands of years ago: China (Murashima, 2002). Therefore, the generic variation between eastern and western culture could be generalized as follows (Tables 16-18):

	Nonverbal Communication	
	Eye Contact	**Facial expression**
Eastern Culture	▪ Less comfortable with direct eye contact ▪ Depends on the social hierarchy ▪ Direct eye contact should be avoided to show respect ▪ Direct eye contact might be inappropriate between men and women	▪ More steady ▪ Relatively conservative
Western Culture	▪ More comfortable with direct eye contact ▪ Shows friendship ▪ Direct eye contact is acceptable between men and women	▪ More abundant ▪ Relatively vigorous

Table 16 Comparison between eastern and western cultures (eye contact and facial expression)

	Nonverbal Communication	
	Gesture	**Tone of Voice**
Eastern Culture	▪ Fewer hand gestures ▪ Excessive use of gestures is considered uneducated behavior	▪ Flat ▪ Relatively calm
Western Culture	▪ More hand and body gestures	▪ Fluctuating ▪ Relatively lively

Table 17 Comparison between eastern and western cultures (gestures and tone of voice)

	Nonverbal Communication	Psychological Care
	Physical contact	
Eastern Culture	▪ Not comfortable with direct touch ▪ Excessive physical contact is considered offensive	▪ Treat the caregiver as a family member ▪ The patient is relatively more dependent
Western Culture	▪ More receptive to direct touch ▪ More comfortable with hands-on care	▪ Treat the caregiver as a friend ▪ The patient is relatively more independent

Table 18 Comparison between eastern and western cultures (physical contact and psychological care)

5.2.2 Cultural Evaluation Form

Other discussion categories of cultural variation in home care, e.g. folk treatments and food service, vary too greatly to be analyzed with tables. Since there are so many cross-cultural and ethnic variations in home care from the case studies, the home caregiver could access a cultural evaluation before assisting the patient by applying the aforementioned categories. This would allow for better understanding of a patient, and subsequently, provide more appropriate home care services. The cultural evaluation could be processed in a written format as follows (Table 19).

Name______________________________ **Patient number**_______________
Citizenship__________________________
Cultural/ ethnic identity_______________ **Religion**_____________________
Age_____________ **Gender** ___________
Languages
First language (Mother tongue)____________________________________
Second language____
Others (if any)____
Etiquette and Social Customs
____
____
Non-verbal Communication Patterns
Eye contact____
Facial expressions____
Tone of voice____
Body gestures____
Physical contact____

Major Health Problems
Current health problem____
History of personal illness____

Food Services
Meal patterns____
Diet restrictions____

Psychological Services
Family structure and decision-making patterns
____
Expectations of the caregiver
____

Table 19 Cultural evaluation form for the patient in home care

This cultural evaluation form supports east-west distinctions addressed above. There are two resources to complete the cultural evaluation by using Table 19 above. The first resource is informed by the patient him/herself and the patient's family, who are the experts on how their culture affects their health beliefs, values, and practices (Lipson & Meleis, 1985). The second resource is a reference guide to various cultures. One excellent resource is Lipson, Dibble, and Minarik's (1996) *Culture & Nursing Care: A Pocket Guide*, which contains information about 24 different ethnic cultures frequently encountered by American nurses in their practice (Narayan, 1997).

Culture is the lens through which we see the world. Leininger describes culture as the learned and shared beliefs, values, and practices that are transmitted intergenerationally and influence one’s thinking and actions (Leininger, 1991). Since culture plays such a crucial role in how a patient feels about and receives home care services, it is essential that caregivers assess the client’s cultural attributes, ethnic identities, and practices (Andrews & Boyle, 1995). Based on the various cross-national literature review, the cultural evaluation form is developed that can assist the caregiver to formulate compressive understanding about the patient, and help construct user profiles for the proposed intelligent home care environment.

The former two case studies (*Section 5.1 and 5.2*) contribute to system design by building the format of knowledge base for user profiles (the home care service profile, the personal taste profile, and the cultural evaluation form). Next section focuses on identifying representative samples from 884 senior subjects for system testing with scenarios.

5.3 Healthy Aging Network Walking Study (HANS)

To develop representative sample types for system testing and evaluation, the Healthy Aging Network Walking Study (HANS) is applied to define the subject's critical characteristics in terms of physical and cognitive functioning, as well as required assistance (William A. Satariano et al., 2010).

5.3.1 Sample Background

HANS is a cross-sectional study of the associations among functional capacity, the neighborhood environment, and walking among older residents in four distinct locations across the U.S (William A. Satariano et al., 2010). The sample comprises 884 people (aged ≥ 65 years) identified through senior citizen organizations in Alameda County CA, Cook County IL, Allegheny County PA, and Wake and Durham Counties NC. These counties, selected from among participating sites in the CDC-funded Healthy Aging Research Network (HAN), reflect a range of weather and topographic patterns.

Prospective participants completed a brief questionnaire to determine eligibility: aged ≥ 65 years, English-speaking, and residing at current address for 12 months or more with no plans to move during the next 3 months. Exclusion criteria included any chronic or serious condition that could limit participation in unsupervised light-to-moderate physical activity, outdoor walking restricted on doctor's orders, self-reported inability to walk outdoors because of a medical condition, or signs of cognitive impairment sufficient to prevent completion of the interview and walking diary. Enrollment was monitored to ensure recruitment of people with a range of self-reported overall health.

Eligible participants were interviewed at the senior organization (78%), in the participant's home (17.4%), or at some other location (3.9%). Informed consent was obtained prior to the interviews, as provided by the IRBs at each of the participating universities: University of California, Berkeley; University of North Carolina, Chapel Hill. The interviews were conducted between September 2005 and November 2007.

5.3.2 Interview Instrument of Healthy Aging Network Walking Study (HANS)

To acquire feedback from the subject of HANS, an interview instrument is utilized for collecting effective data. The data includes on-site direct assessment of physical functioning and self-reported assessments. The questionnaire included demographic and socioeconomic factors; history of chronic conditions and symptoms; history of falls and injuries; physical function and activities of everyday life (activities of daily living [ADLs], instrumental ADLs, Rosow-Breslau and Nagi); cognitive functioning (the Mental Alternation Test and a modified version of the Mini-Mental State Examination); general feelings and depression (Center for Epidemiological Studies Depression Scale)(Kohout, 1993); self-efficacy for walking; social networks and social support; extensive questions on assessments of neighborhood characteristics (Neighborhood Environment Walkability Scale); and levels and types of walking and other forms of physical activity.

HANS comprises 11 categories: 1) General Health, 2) Physical Activities, 3) Physical Functioning, 4) Symptoms and Ailments, 5) Medical Conditions, 6) Cognitive Functioning, 7) General Feelings, 8) Self-Efficacy, 9) Social Network and IADLS, 10) Physical Performance, and 11) Marriage Status. Each category comprises various sub-categories with different variables. Since IHCE focuses on assisting the elderly in terms of physical and cognitive function at home, only parts of the categories and its coordinated sub-categories are chosen for data analysis as follows (Table 20):

Physical Functioning	
Question 9	In the past month, what level of difficulty have you had
9-1	Pushing objects like a living room chair?
9-2	Stooping, crouching or kneeling?
9-3	Getting up from a stooping, crouching or kneeling position?
9-4	Lifting or carrying items under 10 lbs. Like a bag of potatoes?
9-5	Lifting or carrying items over 10 lbs. Like a bag of groceries?
9-6	Reaching or extending one or both of your arms above your shoulder?
9-7	Writing or handling small objects?
9-8	Standing in place for 15 minutes or longer?
9-9	Sitting for long periods, say 1 hr?
9-10	Standing up after sitting in a chair?
9-11	Getting up or down a flight of stairs?
9-12	Walking 2-3 neighborhood blocks?
Question 10	How much help you need to do certain activities. Help could include assistance from another person or use of equipment or an assistive device. At the present time, what kind of help do you need?
10-1	Walking across a room (Prompt: cane, walker, walls)?
10-2	Bathing, or showering?
10-3	Personal grooming (Prompt: brushing your hair)?
10-4	Dressing (Prompt: buttoning a shirt)?
10-5	Eating (Prompt: holding a fork, cutting food)?
10-6	Getting from a bed to a chair, transferring?
10-7	Using the toilet?
Symptoms and Ailments	
Question 12	Please tell me if you've had any of these in the past month
12-6	Problems with your memory?
12-7	Trouble concentrating?
12-8	Trouble seeing steps when going up or down stairs?
12-9	Trouble seeing because of the glare from sun or indoor lights?
12-11	Trouble keeping your balance?
12-12	A need to use the bathroom frequently and/or urgently without warning?
Medical conditions	
Question 15	In the past 6 months have you fallen?
Cognitive functioning	
Question 17	To subtract 7 from 100, and then subtract 7 from the answer you get and keep subtracting 7 until I tell you to stop (Count only 1 error if participant makes subtraction error and subsequent answers are 7 less than the error).

Question 19	What were those three objects I asked you to remember?
General feelings	
Question 24	I am going to read a series of statements about feelings you may have had during the past week. If the statement relates to you, tell me if you felt that way: Rarely or none of the time; some of the time; much of the time; most or all of the time.
24-1	I was bothered by things that usually don't bother me.
24-2	I had trouble keeping my mind on what I was doing.
24-3	I felt sad.
24-4	I felt that everything I did was an effort.
24-5	I felt hopeful about the future.
	In the past week. . .
24-6	I felt fearful.
24-7	My sleep was restless.
24-8	I was happy.
24-9	I felt lonely
24-10	I could not force myself to do what I needed to do.
Social network and IADLs	
Question 27	How many people, including yourself, currently live in your household?
Question 28	Do you have any friends or relatives, who live outside your home, whom you feel close to? (People you feel at ease with, can talk to about private matters, and can call on for help?)
Question 29	Do you currently limit or avoid the following activities because of any health problem, ailment or physical disability?
29-1	House Keeping
29-2	Meal Preparation
29-3	Grocery Shopping
Physical performance	
Question 30-37	A modified version of the Short Physical Performance Battery (SPPB) was used to measure lower-body function, including walking speed examination on a 60-second walk, and one-legged stand. Finally, lower-body strength was measured as the time to rise from a seated position to a standing position five times in sequence with arms folded across the chest. This modified SPPB was summarized in quartiles from poor to excellent lower-body function.

Table 20 Interview instrument of HANS with chosen categories

5.3.3 Statistical Data Analyses for Developing Representative Samples

The retrieved data is analyzed in the categories in terms of overall, gender, and age: females (65-74 years old), females (≥75 years old), males (65-74 years old), and males (≥75 years old). The statistical data of the chosen categories discussed in 5.3.2 is analyzed as follows (Table 21-26):

Physical Functioning						
Question 9	***In the past month, what level of difficulty have you encountered?***					
Level of difficulty (%) / *Types of difficulty*	*Have difficulty*					*None*
	A little	*Some*	*A lot*	*Not Able*	*Total*	
Pushing objects like a living room chair?	15.4601	11.6564	3.0675	1.5951	31.7791	68.2209
Stooping, crouching or kneeling?	21.6686	16.8019	11.5875	2.8969	52.9549	47.0452
Getting up from a stooping, crouching or kneeling position?	27.5229	19.4954	14.9083	1.8349	63.7615	36.2385
Lifting or carrying items under 10 lbs. Like a bag of potatoes?	9.3103	7.4713	2.9885	0.4598	20.2299	79.7701
Lifting or carrying items over 10 lbs. Like a bag of groceries?	16.7064	16.1098	8.1146	1.9093	42.8401	57.1599
Reaching or extending one or both of your arms above your shoulder?	7.5342	6.5068	3.4247	0.4566	17.9223	82.0776
Writing or handling small objects?	7.3780	4.1998	2.2701	0.1135	13.9614	86.0386
Standing in place for 15 minutes or longer?	14.9708	10.8772	4.3275	0.8187	30.9942	69.0058
Sitting for long periods, say 1 hr?	11.8586	7.8677	2.6226	0.2281	22.577	77.4230
Standing up after sitting in a chair?	21.5420	11.5646	3.9683	0	37.0749	62.9252
Getting up or down a flight of stairs?	17.6403	13.5166	7.7892	0.6873	39.6334	60.3666
Walking 2-3 neighborhood blocks?	10.2326	9.6512	4.6512	1.8605	26.3955	73.6047

Pushing objects like a living room chair?	15.4601	11.6564	3.0675	1.5951	31.7791	68.2209

Question 10	***How much help you need to do certain activities. Help could include assistance from another person or use of equipment or an assistive device. At the present time, what kind of help do you need?***				
Required Assistance	*Subjects who require assistance (%)*	*Assistance Provider (%)*			
		A person	*Equipment*	*Both*	*NA*
Walking across a room	6.00	0	42.98	3.51	53.51
Bathing or showering	4.53	5.71	28.57	2.86	62.86
Personal grooming	0.68	6.85	0	1.37	91.78
Dressing	0.79	6.76	1.35	1.35	90.54
Eating	0.23	2.86	0	0	97.14
Transferring	1.13	2.56	7.69	2.56	87.18
Using toilet	1.81	1.19	17.86	0	80.95

Table 21 Statistical Data of physical functioning in HANS

Symptoms and Ailments/ Medical Condition		
Question 12	***Please tell me if you've had any of these in the past month.***	
No.	*Types of Symptoms and Ailments*	*Have Difficulty (%)*
12-6	Problems with your memory?	7.0136
12-7	Trouble concentrating?	3.6405
12-8	Trouble seeing steps when going up or down stairs?	5.9226
12-9	Trouble seeing because of the glare from sun or indoor lights?	16.7800
12-11	Trouble keeping your balance?	13.9932
12-12	A need to use the bathroom frequently and/or urgently without warning?	12.3007
Question 15	***In the past 6 months have you fallen?***	18.79

Table 22 Statistical Data of symptoms and ailments/ medical condition in HANS

Cognitive Functioning			
Question 17	***To subtract 7 from 100, and then subtract 7 from the answer you get and keep subtracting 7 until I tell you to stop (Count only 1 error if participant makes subtraction error and subsequent answers are 7 less than the error).***		
On-site Testing Result	*No Errors (%)*	*One or more Errors (%)*	*Two or more Errors (%)*
Have 2 or more errors in subtraction exercise	44.14	58.9	35.10

Question 19	***What were those three objects I asked you to remember? (recall three objects few minutes later)***		
On-site Testing Result	*No Errors (%)*	*One or more Errors (%)*	*Two or more Errors (%)*
Have 1 or more memory errors	51.64	48.36	15.86

Table 23 Statistical Data of cognitive functioning in HANS

General Feelings		
Question 24	***I am going to read a series of statements about feelings you may have had during the past week. If the statement relates to you, tell me if you felt that way: Rarely or none of the time; some of the time; much of the time; most or all of the time (The data is reported by using the short form of the Center for Epidemiological Studies Depression [CES-D] symptoms index)***	
On-site Testing Result	*Yes (%)*	*No (%)*
Depressed	15.29	84.71

Table 24 Statistical Data of general feelings in HANS

Social Network and IADLs				
No.	*Social Network*	*Current Status*	*Percentage*	
Question 27	***How many people, including yourself, currently live in your household?***	*Lives alone*	48.02	
		Lives with others	51.98	
Question 28	***Do you have any friends or relatives, who live outside your home, whom you feel close to? (People you feel at ease with, can talk to about private matters, and can call on for help?)***	*No*	2.49	
		Yes	97.51	
Question 29	***Do you currently limit or avoid the following activities because of any health problem, ailment or physical disability?***	*Yes*	*No*	*Don't Know*
29-1	Health problem	10.73	89.04	0.23
29-2	Ailment	4.00	95.77	0.23
29-3	Physical disability	4.00	95.89	0.11

Table 25 Statistical Data of social networks and IADLs in HANS

Physical Performance	
Question 30-37	A modified version of the Short Physical Performance Battery (SPPB) was used to measure lower-body function, including walking speed examination on a 60-second walk, and one-legged stand. Finally, lower-body strength was measured as the time to rise from a seated position to a standing position five times in sequence with arms folded across the chest. This modified SPPB was summarized in quartiles from poor to excellent lower-body function. The less physical limitation, the better physical performance.

Level of Physical Limitation	*Level -1*	*Level -2*	*Level -3*	*Level -4 (the weakest physical performance)*
Percent	34.54	31.62	16.34	17.50
Cumulative Percent	34.54	66.16	82.50	100

Table 26 Statistical Data of physical performance in HANS

From the statistical data, aside from physical functioning, the results collected from direct measurement are reported with higher percentages (48.36-65.46 %) than those provided from the self-assessment by the subject (4.00-18.79 %) (Table 27). In general, the subjects are either self-reported or direct-measured to have difficulties in terms of physical or cognitive functioning. However, in question 10, when the subjects are asked about whether they need any assistance (from a person, equipment, or both), only 0.23-6.00 % of the subjects confirm. It indicates that some subjects do encounter difficulties with their physical and cognitive functioning, but they are not quite sure whether they actually need any assistance or are too proud or ashamed to admit it.

This might be due to the follow reasons: 1) the subjects are not quite sure what kind of assistance addressed in the interview could be really helpful, 2) the subjects have limited experience about the assistance addressed in the interview, and 3) the subjects might have dissatisfaction or a lack of confidence regarding the assistance offered.

Self-Assessment		
Physical Functioning		
Question 9	In the past month, what level of difficulty have you encountered?	13.96-63.76 (%)
Question 10	How much help you need to do certain activities. Help could include assistance from another person or use of equipment or an assistive device. At the present time, what kind of help do you need?	0.23-6.00 (%)
Symptoms and Ailments/ Medical Condition		
Question 12	Please tell me if you've had any of these symptoms and ailments in the past month.	7.01-12.3 (%)
Question 15	In the past 6 months have you fallen?	18.79 (%)
General Feelings		
Question 24	Feel Depressed	15.29 (%)
IADLs		
Question 29	Do you currently limit or avoid the following activities because of any health problem, ailment or physical disability?	4.0-10.73 (%)
Direct Measurement		
Cognitive functioning		
Question 17	To subtract 7 from 100, and then subtract 7 from the answer you get and keep subtracting 7 until I tell you to stop (One or more Errors).	58.9 (%)

Question 19	What were those three objects I asked you to remember? (One or more Errors)	48.36 (%)
Physical performance		
Question 30-37	Level of Physical Limitation (≥ Level 2)	1.1 (%)

Table 27 Comparison of statistical data regarding self-assessment and direct measurement

5.4 Conclusion

From the on-site case study, it shows that home care assistance is important in terms of not only the individual categories in ADLs and IADLs, but also the sequence of assistance. For example, the subject in the case study prefers to have the caregiver help her bathe before dinner and join her for a walk after.

By accessing different case studies cross-nationally from literature review, cultural and ethnic variation in home care is researched in terms of verbal and nonverbal communication, food service, psychological service, and folk treatments. Based on these comparisons and discussions, a cultural evaluation form is proposed. This evaluation assists the caregiver in developing a holistic understanding of the patient so as to increase the quality of home care. After all, each individual is a unique blend of multiple subcultures based on ethnicity, religion, socioeconomic status, occupation, geographic location, age, gender, education, acculturation, and creative thinking skills. Awareness of cross-cultural and ethnic variation in home care benefits the caregiver in providing home care assistance specifically appropriate to the unique individual, the patient. Therefore, this evaluation form will be used formulate a personal database in the proposed IHCE. It helps IHCE provide assistance specifically customized to the subject while treating every subject as a unique individual.

Some results regarding the same category of assistance are different in these case studies. For instance, in regards to getting dressed, the subjects reported that they needed assistance dressing in the HANS study around 0.79% of the time. However, dressing was cited as a critical issue for the subject in case study 01 in evaluating the subject's caregivers. This difference might be due to social and cultural variations. The subjects who are particularly concerned with their appearance are most comfortable with care takers that understand and are willing to respect, the subject's personal taste in attire and personal grooming. On the contrary, if the caregiver are neither capable of assisting the subjects to maintain the same taste and preferences in clothing , and are more concerned with the quantity rather than the quality of home care assistance, the subjects' may have a conflict with the caregiver, leading to dissatisfaction and stress, having an overall deleterious impact. Inducted from the aforementioned case studies, four types of sample subjects are generated as personae for system testing and evaluation (Table 28-31).

Type 01		
Name	Alice	
Age	75	
Gender	Female	
Subject's Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	A. has Coronary Heart Disease	Not included
	B. has Hypertension	Not included

	C. has trouble of stooping, crouching or kneeling	52.95
	D. has trouble of getting up from a stooping, crouching or kneeling position	63.76
Cognitive Functioning	E. Percentage reporting 1 or more memory errors (Number of correct responses--recall three objects few minutes later)	48.36
	F. has problems with memory (self-assessment)	7.01
	G. has trouble concentrating H. (self-assessment)	3.64
System Assistance		Subjects who require assistance in HANS (%)
Activities of Daily Living (ADL)	▪ Dressing	0.79
	▪ Bathing/ showering	4.53
Instrumental Activities of Daily Living (IADL)	▪ Housework (Laundry)	Not included
	▪ Meal Preparation	Not included
	▪ Shopping	Not included

Table 28 Sample subject: Type 01

Type 02		
Name	Kevin	
Age	85	
Gender	Male	
Subject's Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	▪ has difficulty of keeping balance	13.99
	▪ use to fall down with two years	18.79
Cognitive Functioning	▪ Percentage reporting 2 or more memory errors (Number of correct responses--recall three objects few minutes later)	58.90
	▪ has problems with memory ▪ (self-assessment)	7.01
	▪ has trouble concentrating ▪ (self-assessment)	3.64
System Assistance		
	1 Medication 2 Falling Monitoring	

Table 29 Sample subject: Type 02

Type 03		
Name	Nancy	
Age	80	
Gender	Female	
Subject's Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	▪ low functionality of vision (nyctalopia)	Not included
	▪ has difficulty of getting up from a stooping, crouching or kneeling position	63.76
Cognitive Functioning	▪ Percentage reporting 1 or more memory errors (Number of correct responses--recall three objects few minutes later)	48.36
	▪ has problems with memory (self-assessment)	7.01
	▪ has trouble concentrating (self-assessment)	3.64
System Assistance		
	▪ Suspicious Circumstances Monitoring	

Table 30 Sample subject: Type 03

Type 04		
Name	Grace	
Age	85	
Gender	Female	
Subject's Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	▪ low functionality of vision (nyctalopia)	Not included
	▪ has difficulty of getting up from a stooping, crouching or kneeling position	63.76
	▪ has difficulty of pushing objects like a living room chair	31.78
	▪ has difficulty of seeing because of the glare from sun or indoor lights	16.78
	▪ has difficulty of Sitting for long periods, such as one hour	22.58
	▪ has difficulty of standing up after sitting in a chair	37.08
Cognitive Functioning	▪ Depression	15.29
	▪ has Problems with memory (self-assessment)	7.01
	▪ has Trouble concentrating (self-assessment)	3.64

System Assistance		Subjects who require assistance in HANS (%)
Activities of Daily Living (ADL)	▪ Transferring	1.13
	▪ Walk across a room (Visual Direction)	6.00
Instrumental Activities of Daily Living (IADL)	▪ Traveling	Not included
	▪ Financial Management	
	▪ Online Shopping	
	▪ Medication	
	▪ Social Network (call for help)	
Others	▪ Pulse and blood pressure measurement	Not included
	▪ Lighting Control	Not included
	▪ Health monitoring (sitting posture)	
Family Member/ Friends (friends or relatives live around/ people the subject feel at ease with, can talk to about private matters and can call on for help)	Veronica (daughter)	97.51

Table 31 Sample subject: Type 04

Each type of representative samples is defined in terms of the subject's name, age, gender, characteristics of physical and cognitive functioning, and proposed system assistance. Type 01 is designed for demonstrating how IHCE will assist the subject regarding ADLs and IADLs, while type 02 and 03 serve as examples of safety issues and system responses (code blue), e.g. falling and suspicious circumstances monitoring. Type 04 is defined for validating one-day synthetic scenario evaluation from the midnight until the afternoon. The details of scenario testing and evaluation will be discussed in *Chapter VII*. The next stage of the research will probe into system development and testing, including the construction of IHCE, the multi-agent system, interface design, and the underplaying theories.

PART III

System Development and Testing

Part III comprises two chapters and sheds light on formulating the proposed Intelligent Home Care Environment (IHCE), including system development, testing, and evaluation. Chapter VI illustrates how to apply Acupuncture Theory as a metaphor to develop the new system, Dynamic Mulit-Agent System (DMAS), and how the physical setting of IHCE should be formulated, including space composition and human-environmental interface design. Chapter VII covers system testing and evaluation with different types of scenarios, including reactive/proactive assistance in activities of daily living/ instrumental activities of daily living, safety issues (code blue, e.g. falling and suspicious events monitoring), and other multiple activities.

Chapter VI

System Development of Intelligent Home Care Environments

This chapter elaborates on the mechanism of system development of Intelligent Home Care Environments (IHCE) that may be discussed from two perspectives: 1) computational system design and 2) physical environmental design. Regarding computational systems, this research applies Acupuncture Theory as a metaphor for designing Dynamic Multi-Agent Systems (DMAS). Physical environmental design involves designing space layouts, smart appliances, human-environmental interactions, and interface design.

6.1 Applying Acupuncture Theory as a Metaphor/ Model

In thinking of intelligent-built environments as living ecology, acupuncture theory is a useful metaphor that provides a holistic viewpoint of the human body based on the optimization of energy flowing in-between the environment and the human body.

Acupuncture is one approach among several different treatment modalities within Traditional Chinese Medicine (TCM). When energy is unobstructed, the body’s functions are optimal, and the overall system, the body, is considered healthy. When energy flow is hampered, acupuncture treatment seeks to restore that energy balance by the insertion of fine needles into specific points along twelve channels under the skin to restore an unhindered flow of energy (Fig. 19).

Fig. 19 The concept of energy flow between human body and the environment through human skin

6.1.1 The Manifestation of Yin and Yang from the Macrocosm to the Microcosm

According to the most essential text of Traditional Chinese Medicine (TCM), *The Yellow Emperor's Classic of Medicine* (Ni, 1995), which was edited several thousand years ago, all of the energy existing in the cosmos could be categorized as yin or yang, including the energy in human bodies. Energy, also called Qi in TCM, must be distributed and expelled evenly between human bodies (microcosm) and the greater environment (macrocosm) so that humans maintain health and remain adaptable to dynamic environments and situations.

Meanwhile, Qi in the human body is composed of "internal Qi" and "external Qi". External Qi represents the flow of Qi on the surface of the human body, while internal Qi is the flow of Qi inside the three Dan-Tains (the source of inner energy) of the human body, distributed between all organs and tissues (Ming-Tung Chen, 2000). Since external and internal Qi are intertwined and interact with each other, patients can be diagnosed and treated by adjusting the flow of external Qi.

6.1.2 Acupuncture Points and Twelve Channels and Collaterals

Acupuncture theories contain two essential ingredients: acupuncture points and twelve channels and collaterals. Acupuncture points are entrances that mediate energy going through human bodies. Receiving stimuli from different acupuncture points could stimulate processes and adjust the operation of specific organs and various systems or transmit messages throughout the entire body to modify holistic energy conditions (Ming-Tung Chen, 2000) (Fig. 20).

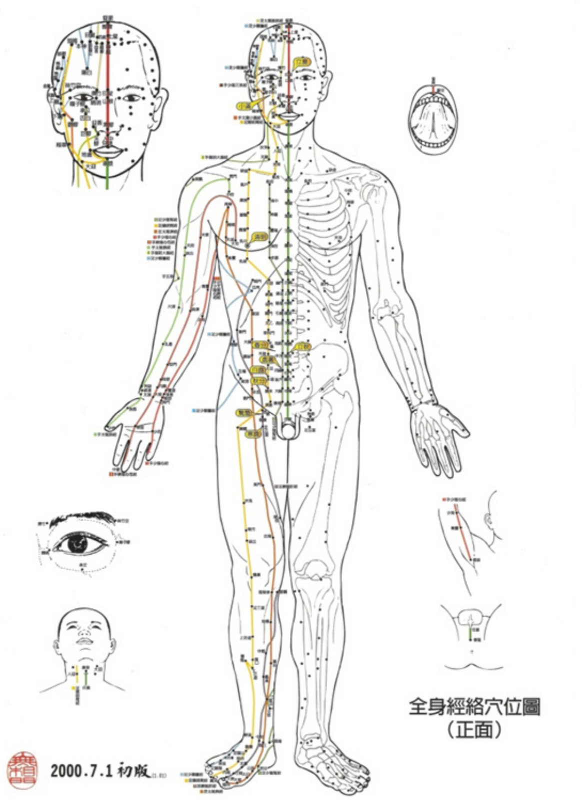


Fig. 20 The illustration of acupuncture points (Ming-Tung Chen, 2000).

There are over 1,000 known acupuncture points on the body, distributed among twelve main channels and collaterals all over the skin. Qi from the macrocosm goes through these acupuncture points, guided and conducted within these twelve channels and collaterals, and reaches the inner organs and tissues. Channels and collaterals is a translation of the Chinese term “Jingluo.” “Jing” has a geographical connotation and means a channel (e.g. a water channel) or longitude (Deadman et al., 2007). Using the functions of a tree for illustrative purposes, the “Jing” is like the trunk and main branches of the channel network. They generally run longitudinally through the body at a relatively deep level and connect with the internal organs. They comprise the twelve primary channels, the eight extraordinary vessels and the twelve divergent channels. “Luo” refers to the finer branches of the channel network, which are more superficial and interconnect the trunk and main branches (jing), the connective tissues and cutaneous regions.

Like the layered structure of the twelve channels, the control scopes of each acupuncture point are various and at different levels of the hierarchy based on the function of the channels to which they are connected. Some acupuncture points control single organs or functions while others are responsible for multiple functions or entire body systems. For instance, to improve the urinary function of kidneys, it is necessary to first adjust the central circulatory system to guide more blood into the kidneys, specifically enhancing the filtering function of the glomerulus and harmonizing the kidneys with other organs to bring the entire body into an energy balance (Maciocia, 2008).

Acupuncture theory posits that the human body has various acupuncture points that receive Qi and stimuli separately. Consequently, Qi and these stimuli will be translated through layered, hierarchically centralized channel network systems to adjust internal organs to keep the body in balance and healthy. If we take the acupuncture theory as a metaphor to discuss the application of intelligent agents of Intelligent Environments, an ideal IA frame should contain both centralized IA and distributed IAs owing to different levels of ability – integrating and analyzing inputted data, providing solutions, making decisions, and solving conflicts.

6.1.3 Five Phases and Correspondences in Acupuncture

From the viewpoint of Traditional Chinese Medicine, the composition of the human body can be categorized to five phases: wood, fire, earth, metal, and water. Each phase has corresponding associations with different organs, tissues, and mechanisms of human body, and has a unique representative color (Fig. 21) (Ming-Tung Chen, 2000; Veith & Rose, 2002). This rationale is applied to the acupuncture points and energy channels as well. Some acupuncture points are more powerful, having an impact on or acting as a gateway to various organs or systems in the body, while some have more specific or limited ability to control a certain organ or system.

The Five Phases & Correspondences

Wood Fire Earth Metal Water

	WOOD	FIRE	EARTH	METAL	WATER
VISCUS	liver	heart	spleen	lung	kidney
BOWEL	gallbladder	small intestine	stomach	large intestine	bladder
SENSE ORGAN	eyes	tongue	lips	nose	ears
VISCUS STORES	blood	shen (spirit)	nutritive qi (chyle)	qi	jing (sexual essence)
TISSUE	tendons	vasculature	muscles	skin	bones
QUALITY	color	odor	flavor	tone	fluid
EXPRESSION	shout	laugh	sing	weep	groan
INDICATOR	nails	complexion	lips	breath	hair
SEASON	spring	summer	midseasons	autumn	winter
DIRECTION	east	south	center	west	north
COLOR	bluegreen	red	yellow	white	black
ODOR	rancid	scorched	fragrant	fishy	putrid
FLAVOR	sour	bitter	sweet	spicy	salty
EMOTION	anger	frivolity	worry/obsession	grief	fear/fright
ADVERSE CLIMATE	wing	heat	humidity	dryness	cold
STRESS RESPONSE	clenching	depression	hiccough	cough	trembling

Fig. 21 The five phases and correspondences in Traditional Chinese Medicine (Huan, Rose, 2001)

6.1.4 A Holistic Intelligent Multi- Agent Intelligent Environment

Inspired by following Acupuncture Theory as a metaphor [15], a holistic intelligent environment needs not only to be multi-agent-based that has multiple IAs coping with various situations, but also to have IAs assigned to higher levels of the hierarchy capable of making decisions that solve conflicts between the IAs at a lower level. This holistic IA system contains both centralized IAs and multiple distributed IAs that can both interact with multiple occupants' behavior separately, and have the ability to make decisions from a holistic viewpoint. Just like the rationale of acupuncture points, the system is composed of multiple levels of IAs. Each level has its specific function and limitation of ability to interact with occupants or propose solutions. Once there are conflicts between IAs in the same level, other IAs at the next higher level would be interfering to mediate the conflicts and propose optimized solutions.

6.2 Dynamic Multi-Agent System Development (DMAS)

In thinking of intelligent-built environments as living ecology, Acupuncture Theory is employed as a metaphor that elaborates a holistic, systematic approach of the human body based on the optimization of energy flowing between the environment and the human body (Ming-Tung Chen, 2000; Zhang & Rose, 2001). It comprises numerous acupuncture points that function, cooperate, and are managed based on multiple subsystems (Ming-Tung Chen, 2000).

6.2.1 Multiple Subsystems and the Dynamic Hierarchy

In Acupuncture Theory, energy flows in and out of the human body through five main acupuncture points which sit at the top of the acupuncture system. Acupuncture points are categorized in five phases with different attributes (Fig. 22). The size of the point in the diagram represents the activeness and control scope of each acupuncture point toward the human body (Deadman et al., 2007). Acupuncture points are distributed based on twelve energy channels and collaterals (Jingluo). Each channel has multiple acupuncture points belonging to various phases (Deadman et al., 2007; Ming-Tung Chen, 2000). This mechanism shapes a fundamental hierarchy based on the twelve energy channels (the black dotted lines). In response to the ever-changing status of human body, the hierarchy of acupuncture theory is dynamic: acupuncture points not only cooperate based on the twelve energy channels, but also collaborate according to other multiple subsystems, e.g. five phases (the yellow and blue lines) and biological systems (e.g. immune system and digestive system) (Deadman et al., 2007; Ming-Tung Chen, 2000).

[15] The proposed Intelligent Multi-agent Intelligent Environment is inspired by Acupuncture Theory as a metaphor. The ideation and rationale of the proposed Intelligent Environment stand on its own.

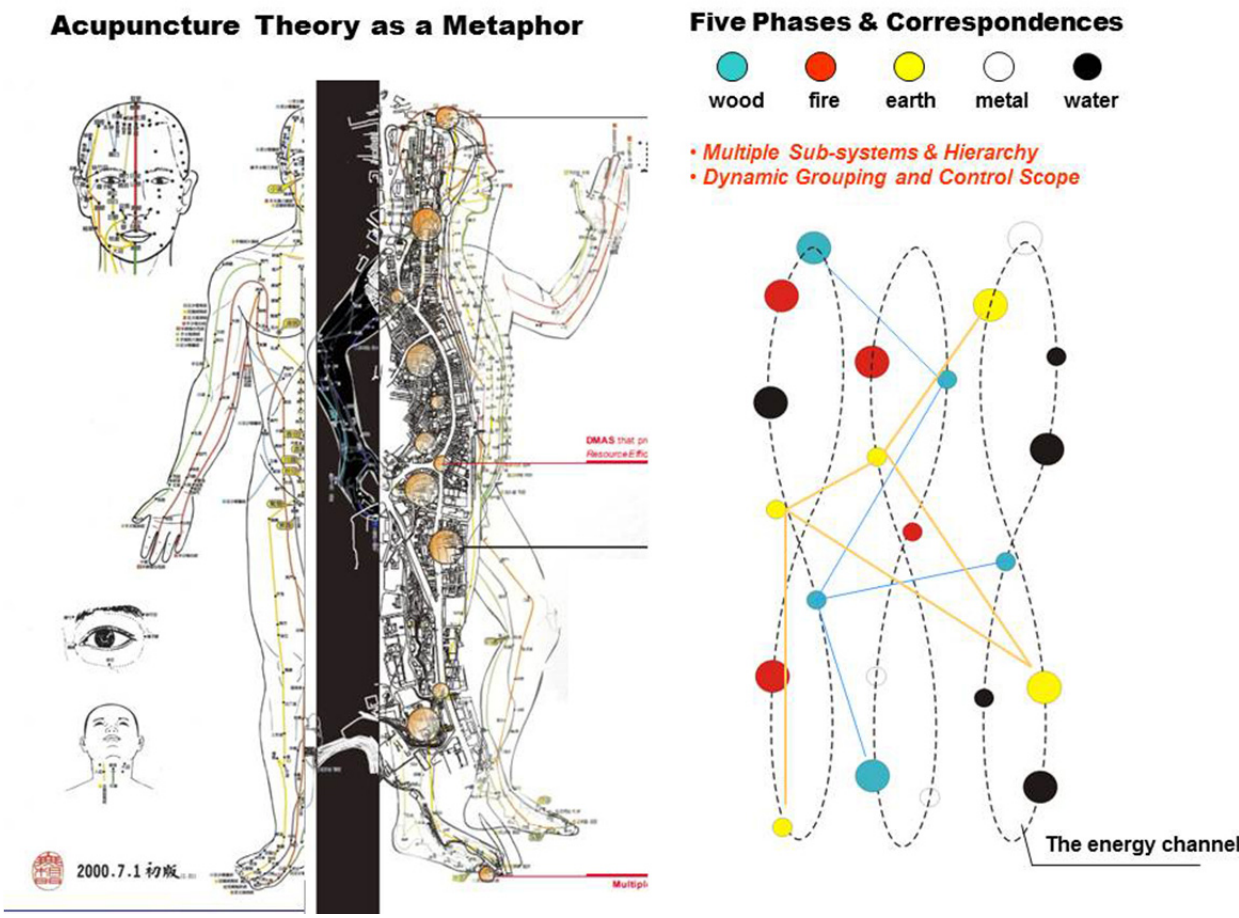


Fig. 22 The diagram of multiple subsystems and the dynamic hierarchy in the Acupuncture Theory (the original illustrations of Acupuncture System is made by Min-Tung Chen, 2000)

6.2.2 Dynamic Grouping and Control Scope

In Acupuncture Theory, patients are not diagnosed solely based on their specific symptoms, but examined and assisted in terms of multiple systemic diagnoses in a search for underlying causes (Ming-Tung Chen, 2000; Veith & Rose, 2002). In Traditional Chinese Medicine, the systematic diagnoses/ therapies contribute not only to realizing what the problem is (result of illness caused by energy conflicts), but also to uncovering how symptoms might be caused (origin of illness). Accordingly, the medical professionals can assist the patient by removing the possible origin of illness, curing their symptoms thoroughly, and even avoid similar health problems (avoid possible energy conflicts) from happening in the future (Ming-Tung Chen, 2000).

Different systematic diagnoses/ therapies correlate to a diverse group of acupuncture points. Meanwhile, the activeness and control scope of each acupuncture point might vary accordingly (Ming-Tung Chen, 2000). For instance, acupuncture point α serving as the main character in the immune system might only have secondary control over the digestive system. Also one acupuncture point might have more than one attribute managed by different subsystems simultaneously. Instead of being static and confined, the hierarchy/ grouping of acupuncture points is a dynamic one that provides abundant flexibility.

6.2.3 System Structure and Optimization between Safety, Resource Efficiency, and Adaptability

Taking the rationale of Acupuncture Theory as a metaphor, to respond to ever-changing human needs, the proposed Intelligent Home Care Environment (IHCE) contains a Dynamic Multi-Agent System (DMAS) that comprises dynamic hierarchies and groupings. The mechanism of making hierarchies dynamic is determined by cooperation between top agents (as the five main acupuncture points). To better interact with the occupants and avoid possible conflicts, except responding to the occupant's each action individually, the IHCE could interact with its occupants systematically, paying more attention on the causality and continuity of human behavior (Latour, 2007; Thrift, 2007). Accordingly, the top agents could formulate different groups of agents to respond to numerous human activities in the physical environment. In the meantime, like the dynamic control scope of acupuncture points, each intelligent agent's duty is adjustable in order to adapt itself better into different groupings.

The proposed Dynamic Multi-Agent Structure (DMAS) is structured in dynamic hierarchies and comprises with three types of distributed intelligent agents from top to bottom in sequence: three Environmental Optimization Agents (EOA), Scheme Management Agents (SMA), and Object Agents (OA) (Fig. 23).

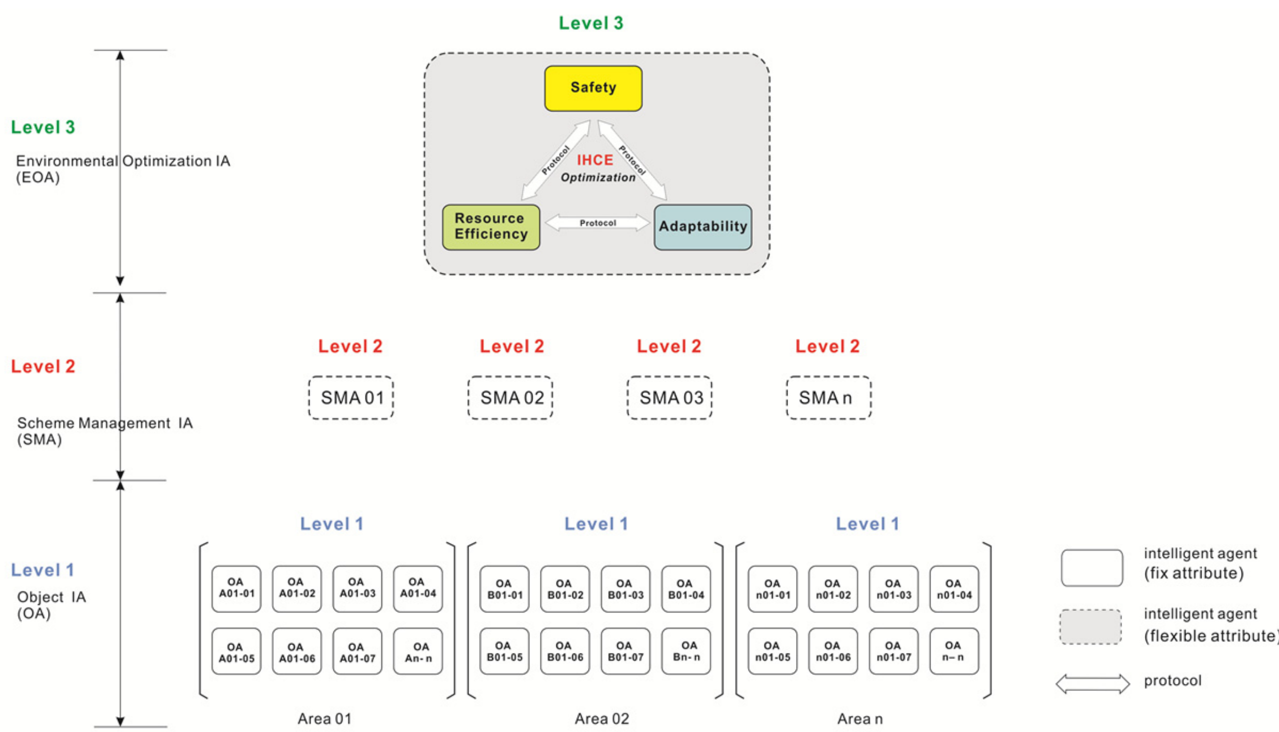


Fig. 23 The diagram of Dynamic Multi-Agent System (DMAS)

1) **Environmental Optimization Agent (EOA)**: EOAs are at top of entire Dynamic Multi-Agent System and are responsible for providing an optimized solution from a macro viewpoint among safety, adaptability, and resource efficiency. Each EOA has its own knowledge base regarding different expertise. Here are three types of EOAs: *Safety Agent*, *Adaptability Agent*, and *Resource Efficiency Agent*.

- **Safety Agent**

Regarding optimization in home care, the first priority is the user's safety. Safety represents the maintenance of the user's health and well-being. The standards of Safety Agent should be customized according to the user's personal status, e.g. the user's history of present illness (HPI). It also should be flexible and responsive to the changes of the user's physical and cognitive function.

- **Adaptability Agent**

Regarding the user's inhabitation in the environment, "adaptability" is defined as the usability and appropriateness that an environment could provide to support multiple, dynamic activities based on the user's social/ cultural background, e.g. personal and cultural tastes. An ideal intelligent environment in home care should be able to adjust on its' own, helping users function in the physical environment appropriately, and increasing users' comfort and convenience both physically and psychologically.

- **Resource Efficiency Agent**

The proposed intelligent environment assists the elderly within limited resources. *Resource Efficiency Agent* involves budgeting both the construction and maintenance of an entire intelligent environment system. Regarding sustainability, natural resources are precious and limited as well. An intelligent environment for home care is expected to help the patient effectively and run efficiently enough to conserve natural resources.

These three IAs can cooperate as a single entity, IHCE, to receive information, understand events, and generate system goals accordingly. Once a system goal is confirmed, IHCE will divide it into different schemes (sub-goals), and assign these schemes to SMA(s) for execution (Fig. 24). Meanwhile, these three IAs may receive individual inputs as well. For instance, Input 01 for *Resource Efficiency Agent* provides information of the current resource consumption. This allows the system to know the present limitation of resources, e.g. energy distribution. Input 02 for *Safety Agent* deals with the user's history of present illness (HPI), enabling the system to apply the appropriate level of safety standard for the user and continually keep that information up- to-date.

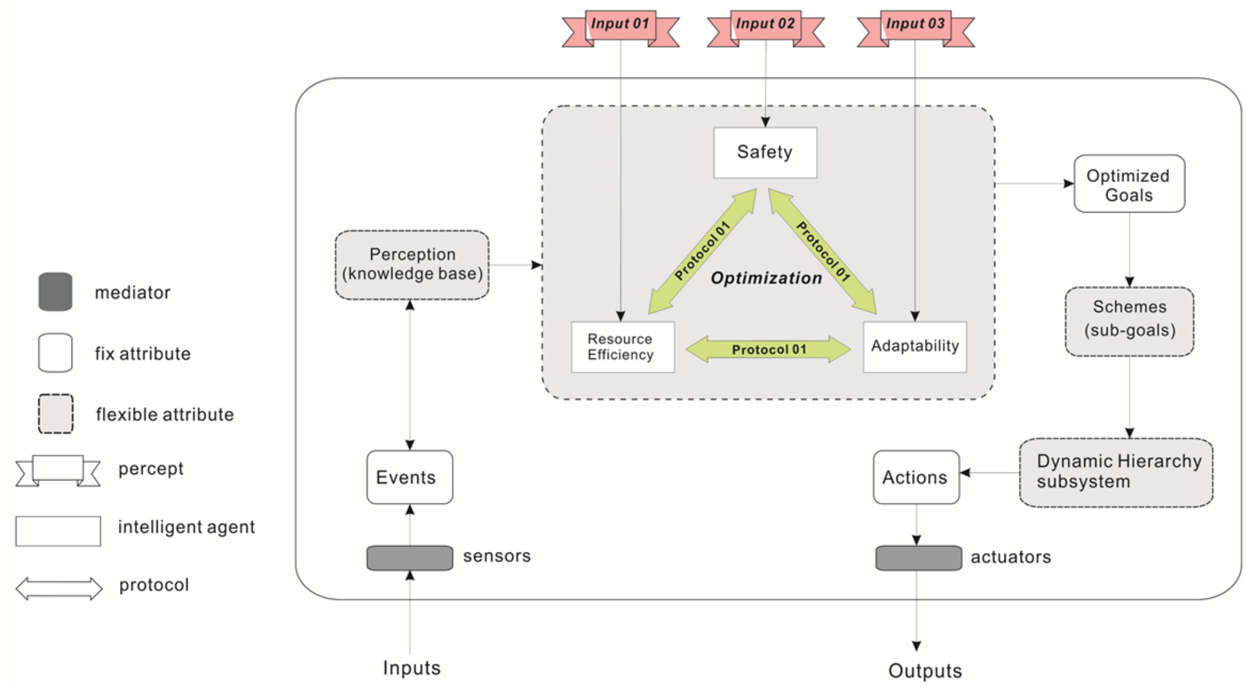


Fig. 24 The optimization diagram of Intelligent Home Care Environment (IHCE) IA

2) **Scheme Management Agent (SMA):** The SMA serves as a coordinator/ manager of OAs and is tasked with managing optimized solutions proposed by Environmental Optimization Agents (EOA). Each SMA could be seen as a team leader that is assigned by EOAs for executing optimized schemes (sub-goals) and solving conflicts between OAs. Functioning as different subsystems in acupuncture theory, each SMA can modify its control scope, formulating a dynamic hierarchy/ grouping to manage a specific group of OAs according to various human activities and demands. When OAs in the same group conflict one another, the SMA will either coordinate by itself or consult with EOAs for an optimized solution from a macro viewpoint. The number of SGA in the system varies according to the complexity of missions generated by EOA.

3) **Objects Agent (OA)**: OA is responsible for controlling behaviors of different objects in the physical environment, e.g. chairs, windows, doors, etc. Each OA comprises sensors and actuators to receive stimuli and interact with the user in the physical environments. When OA is triggered by the user, it retrieves the user's data from the user profile, identifying the activities from its built-in knowledge base, and performs an action(s) according to the capacity of the object recorded in the object profile. OAs are categorized according to the special relationship/ areas (e.g. living room/ rest room) in the physical environment without any confined hierarchy or grouping.

6.3 Formulating Physical Environments of IHCE

To formulate the physical environments of IHCE for scenario testing and evaluation, this research proposes a hypothetical physical environment designed for a single elderly person. This section involves three perspectives for discussion: 1) space composition, 2) human-environmental interaction, and 3) human-environmental interface design.

6.3.1 Space Composition

The proposed hypothetical environment is an example of a living unit in the apartment that comprises the following spaces: one bedroom (for the user), one guest room (for the caregiver or friends visiting occasionally), one bathroom, a living room, a kitchen, and a dining space (Fig. 25). Each space comprises various smart appliances that can assist users with physical and psychological functioning. The details of all the smart appliances will be introduced with the scenarios in *Chapter VII*.

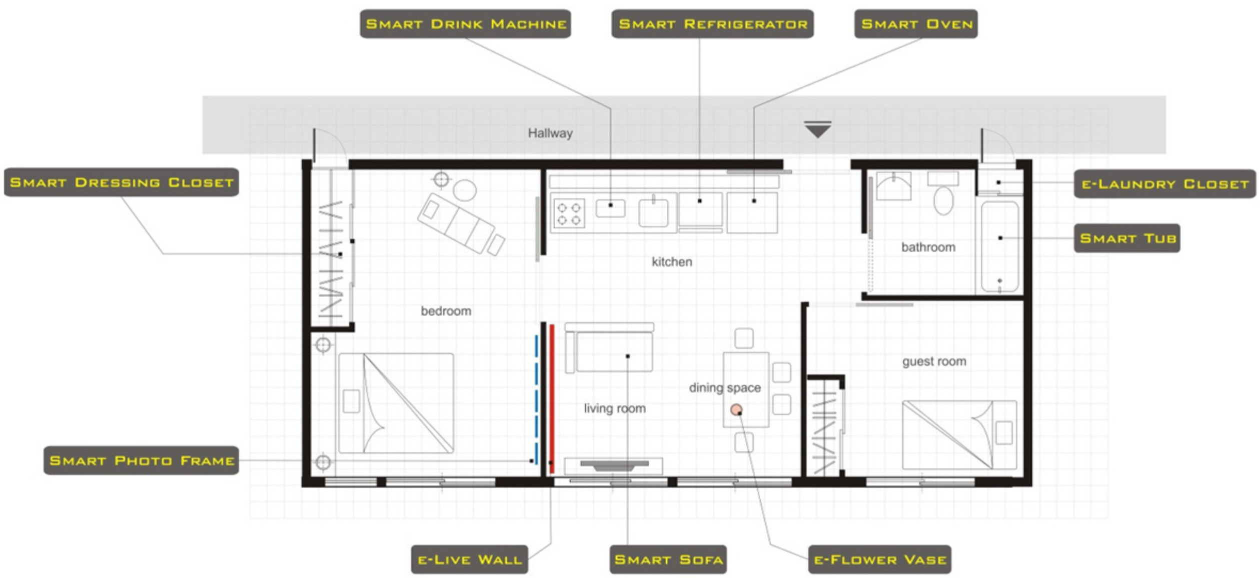


Fig. 25 The space composition of the proposed Intelligent Home Care Environment (IHCE)

6.3.2 Theories of Human-Environmental Interaction

To explore how the interface between the occupant and his environment should be designed to benefit the elderly in IHCE, this section reviews several theories of human-environmental interaction as the underlying theories. These theories span different disciplines, including the epidemiology of aging (Lawton's Press-Competence Model), sociology (Actor-Network Theory and Non-representational Theory), social/ cultural factors (Taste Theory), body-mind consciousness (Body Conscious Design), and human-computer interaction (Tangible User Interface).

1) A Gerontological Approach: Lawton's Press-Competence Model

Developed from earlier scholarship on the epidemiology of aging and gerontology, Lawton and Nahemow proposed another ecological model, the General Ecological Model of Aging, which focuses on human behavior and well-being. The main argument of this model is that human function and behavior result from the competencies of the individual, the demands or "press" of the environment, and the interaction or adaptation of the person to the environment (Lawton & Nahemow, 1973). According to the theory, the interrelationship between individual competency and the environment is dynamic. Both individual competencies and environmental press change during aging process. This rationale is presented in the "Press-Competence Model" (Fig. 26) by Lawton and his colleagues in 1973 (Lawton & Nahemow, 1973; Satariano, 2006).

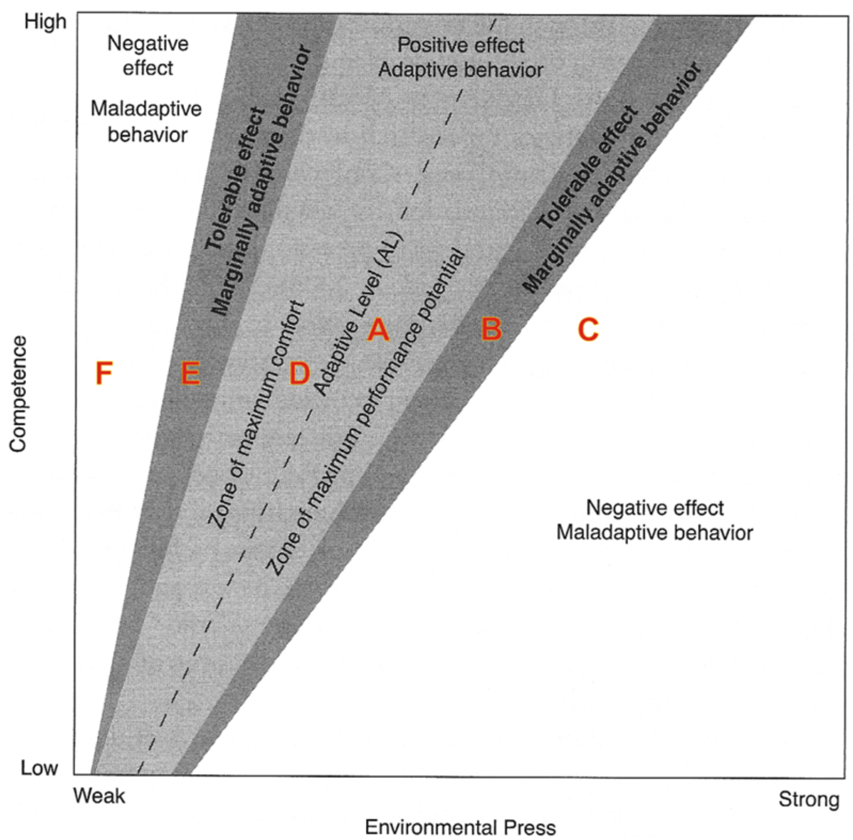


Fig. 26 Lawton and Nahemow's Press-Competence Model (Lawton & Nahemow, 1973; Satariano, 2006)

Competence lies on a continuum from low to high along the vertical axis, while environmental press moves from weak to strong, along the horizontal axis. The dotted line in the middle moves from low to high along both axes, representing adaptation, the theoretical point at which the level of individual competence matches the level of environmental press. With aging, individual competence is on a generally falling trend line. Should environmental press remains constant, individual behavior and functions are affected adversely. Different meanings of Zone A~E are explained as follows:

Zone A: This area is characterized by high environmental press and challenges. It encourages active behavior.

Zone B: This is a marginal zone within which individuals are still able to function, but with some difficulty. Falls, stress, and other indicators of maladaptive behaviors start occurring here.

Zone C: In this area, the environmental press exceeds the individual's ability for adaptation and starts to cause disablement (Verbrugge & Jette, 1994).

Zone D: This area is characterized by weak environmental press and a general relaxation from environmental demands.

Zone E: This is another marginal zone that the absence of environmental stimulation begins to lead to boredom.

Zone F: In this area, the environment is so unchallenging that it contributes to functional passivity, disuse, and limitations. It might lead to a sense of "helplessness" (Peterson, Maier, & Seligman, 1993; Seligman, 1975)

2) Sociological Approaches: Actor-Network Theory and Non-representational Theory

▪ Actor-Network Theory

Bruno Latour explains the human-environmental relationship from a social perspective referred to as Actor-Network Theory (ANT). Latour interprets human-environmental interactions through a social network comprising both humans and objects as participants (Latour, 2007). Different from the traditional definition of sociology, these participants are not endowed with confined social rules or social ties. The network and interrelationship exists only when these participants take actions together as an assemblage (Fig. 27). Multiple assemblages formulate the social (the collective). Instead of describing a static relationship, ANT elaborates a dynamic, continuous movement within which participants explicitly engage in the reassembling of the collective.

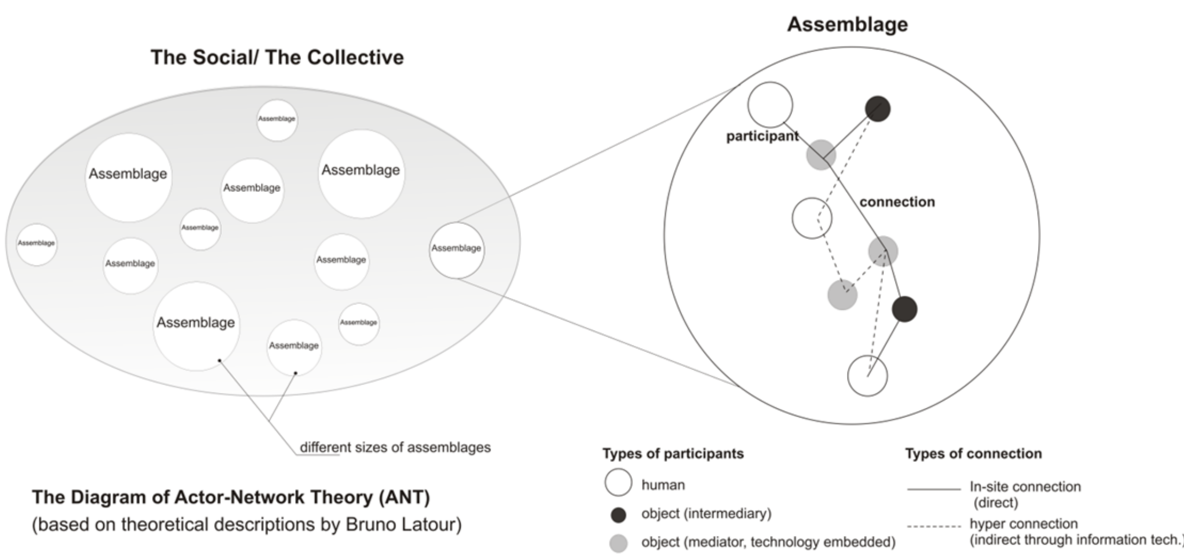


Fig. 27 The diagram of Actor-Network Theory (ANT)

In the aforementioned theories, physical environments and object elements are interpreted or manipulated by humans passively. Yet objects are social actors taking actions actively and have agency[16] as humans in ANT. Two types of objects are categorized:

An intermediary: transmit information and message without any transformation. It transports meaning or force without transformation. It defines its inputs enough to define its outputs, e.g. a hammer.

A mediator: it is uncountable and unpredictable. It transforms, translates, distorts, and modifies the meaning of the elements they are supposed to carry, e.g. a credit card.

The main factor to clarify between an intermediary and a mediator is technology, especially information technology. Having information technology embedded in the objects allow us to trace the associations in a more transparent way than before. For instance, in a supermarket, labels and bar-codes have the capacity to provide you with the possibility of carrying out calculations somewhat more accurately. People are sustaining this mental and cognitive competence as long as they subscribe to this equipment.

In Lawton's theory, physical environments and elements are discussed from their negative attributes as "press," yet ANT treats physical objects positively as "participants" in the human-environmental network in the same way as human beings. Facilitated by technologies, these physical elements can affect and broaden the man-made environmental network into a larger, dynamic collective. Assisted with technologies in ANT, the network can increase human sensorium, extend the cognitive periphery of physical environment, and make environmental affordance more adjustable accordingly.

- **Non-representational Theory**

Affected by Actor-Net Theory, Nigel Thrift proposed Non-Representational Theory (NRT) as a way to illustrate the human-environmental relationship in a new approach to geography (Thrift, 2007). Instead of existing in a static, Newtonian grid, NRT argues that human life is based on and in movement, the "onflow" as Ralph Red calls it, of everyday life. There is no stable "human" experience because the human sensorium is constantly being re-invented as the body continually adds parts in to itself. How and what is experienced as experience is itself variable. Besides, humans have an "affect," the emotional factors reacting to the physical environment. Affect is a form of thinking that can increase or decrease the ability of the body and mind alike to act (Thrift, 2007).

Thrift proposed that consciousness of perception is too narrow. Ambient sense is important, e.g. social awareness17. The most effective approach is a new empiricism that differs from a sense-perception or observation-based empiricism. Information Technology (IT) can help

[16] Agencies are presented in an account as doing something, that is, making some difference to a state of affairs, transforming some As into Bs through trails with Cs (Latour, 2007).

[17] Social awareness involves high-level cognitive abilities like imitation, learning about learning, and an n ability to carry meaning in a whole series of registers and the manipulation of time and space. It predominates over sensory awareness.

formulate the new empiricism by positing continuity, the lineage of inter-relation within a human-environmental network. Thrift defines one characteristic of IT as "qualculation," an activity, which allows millions of calculations to continually be made in the background of any encounter (accelerated by computing power), e.g, bar-codes. Calculation is becoming an ubiquitous element of human life, implemented by small bits of hardware and software.

Driven by the power of technology, the human body can co-evolve with things, take them in and add them into the biological body, as a "body-in-action." Powered by qualculation, Thrift proposes the idea of "new sensorium": The body schema extends beyond the body's physical limit through the assistance of technologies. The body is defined by how it is moving in relation to other objects.

Through multi-linking, the body can touch more than one site at a time. A new relationship of time and space is generated accordingly: space becomes relative rather that absolute. Meanwhile, space can keep on changing its characteristic and meaning. For instance, people living in different time-zones can have a simultaneous virtual meeting using web-cams and the Internet. The boundary of space for this activity becomes blurred and different from the actual physical locations of the participants.

Lawton's theory positions the physical environment as a confinement that brings limitation to the occupants. Conversely, Thrift proposed that the physical environments endowed with IT are transparent, unlimited, and can help people formulate a new sensorium and extend cognition of their living environment, and partially rid themselves of the limitations of both time and space18.

3) A Social/ Cultural Approach: Taste Theory

Taste Theory is a social-cultural concept proposed by Galen Cranz (Cranz, 2004). Taste Theory provides a way of observing and evaluating physical environments that people create. It focuses on the ordinary practice of decorating homes[19]. Sociologists view taste as a way that people make distinctions between themselves and others and legitimate class differences. Cranz suggests that taste can be seen as a form of social differentiation (Cranz, 2004).

Taste Theory can be demonstrated as a formula as follows:

Taste = (Pragmatics + Symbols) Integrated Aesthetically

Taste Theory categorizes two types of objects:

1) *Pragmatic object*: an object that contains cultural utility, (e.g. a knife in the kitchen)
2) *Symbolic object*: an object that represents individual identity (e.g. a family photo on the wall)

However, neither the pragmatic nor the symbolic categories are fixed. They vary culturally. Context is essential for identifying whether objects are pragmatic or symbolic. For instance, a plastic chair near the dining table might be a pragmatic object (a tool), while a chair on display in

[18] In non-representational theory, Thrift mentions that there are multiple spaces and times, not one Newtonian grid. Time and space are consequences, relating to one another.

[19] Interior decoration is defined broadly as a widespread general cultural practice of decorating the interior of a room or house (Cranz, 2004).

a museum might have symbolic significance as an art piece or for its historical significance. Sometimes an object is both pragmatic and symbolic. A tea cup with a representation of a dragon tattoo may serve both as a practical drinking vessel while representing the user's identity.

Aesthetic integration is a psychology of assemblage that involves aesthetic viewpoints (e.g. the sense of symmetry and color coordination) and kinesthetic perception (e.g. the awareness of bodily movement). It is a process of selection and assembly. In this dissertation the author adds that an appropriate aesthetic integration can *amplify* the functioning of pragmatic elements and demonstrate individual identity through symbolic objects.

Comparing Lawton's statement to Taste Theory, the environmental press should be discussed not only from kinesthetic viewpoint, but also from psychological issues caused by individual taste. For instance, two rooms having the same special arrangement of furniture may cause the same degree of environmental press according to Lawton's theory; however, the particular color, texture, or style of the furniture will represent issues of taste and may influence the cognitive status of the occupant and even their personal competence.

4) A Body-mind Approach: Body Conscious Design

Body Conscious Design (BCD) provides a new way to think of human-environmental interactions by rethinking the body-mind relationship and proprioception (Cranz, 2000). Cranz proposes three somatic principles: 1) philosophical ideas about the human body; 2) ideas about anatomy; and 3) ideas about psycho-physical processes. These three aspects affect one another. BCD starts from a proposition that the mind and the body should be one entity, the "body-mind." Different from the encoding-decoding process between perception and cognition (Rapoport, 1990b), Cranz states that conception is another form of perception (Cranz, 1990). As many body workers can sense with their hands, humans have more than five senses.

"Chair reform has its limits. No chair is perfect, partly because no posture is perfect (Cranz, 2000). As a species we are designed for movement. The best posture probably is the next posture (Cranz, 2010)."

— *by Galen Cranz*

In ergonomics, the study focuses on the relationship between people and machines, and tends to treat people as machines with interchangeable parts (Bennett, 1977). However, in BCD, the human body is thought of as close to a tensegrity structure (Fuller, 1965)—a dynamic structure in a well-balanced combination of tension and compression. The human body works best in multiple postures—postural pluralism (Cranz, 2000). To emphasize that the human body is a dynamic system, teachers of the Alexander Technique even tend to apply the term "use" instead of "posture." "Use" implies movement over time, a pattern of coordination and volition, whereas "posture" connotes a static fixed position (Cranz, 2000).

The concept of "comfort" should be rethought from the original Latin word meaning "to strengthen." From the viewpoint of BCD, an environment should well support multiple postures and encourage people to "use" their bodies themselves in different ways. A physical environment providing too much external support[20] might prove harmful to the human body over an extended

[20] By the end of the 19th century, the word "comfort" came to mean "support" or to make easier by providing outside external support (Cranz, 1990).

period. Lawton's Press-Competence Model illustrates the same idea. Once the environmental is too unchallenging (over supportive), it contributes to functional passivity, disuse, atrophy and limitation, and might lead to a sense of "helplessness" (Satariano, 2006; Seligman, 1975).

5) A Technological Approach: Human-Computer Interaction

Following the digital revolution, two trends lead us to rethink the ways we interact with computers, as well as how we can benefit even more from them: 1) the increasing computational power, and 2) the expanding context that computers affect our life, e.g. ubiquitous computation. These trends affect human behavior and how humans interact with their physical environment. For instance, a traditional public library provides a large space for storing physical books. A new public library in the digital era can convert physical books into digital formats that sharply reduce the needs for book storage. Meanwhile, a variety of digital media other than books are available to the public for learning and research, e.g. videos and other digital archives. Consequently, the human-environmental interaction in a new library embracing digital media is wildly different from the experience of a traditional library. How humans interact with computers becomes an essential concern regarding physical environmental design.

A research domain, Human-Computer Interaction (HCI), has initiated an exploration of different ways to control and interact with new types of computer systems, including developing new prototype systems, discovering new forms of interaction, and generating new designs.

> *"Our experience using computers reflects a trade-off made more than 50 years ago. We are now in a position to reconsider the trade-off."*
>
> *by Paul Dourish, 2001*

As the evolution of computers, HCI has its own history of processing changes as well. Dourish proposes an evolutionary history of HCI based on different sets of human skills that can be summarized as follows:

Electrical → Symbolic → Textual → Graphical → Embodied

a) Electrical

Initially, the word "computers" referred to human beings— people who are responsible for figuration of calculations. Prior to the invention of digital computers, there were analog computers. Analog computers relied on the use of standard components to create electronic models of continuous natural phenomena, e.g. wave motion, the interaction of electronic forces, etc. Gradually, the ways people interact with computers evolved from analog electronics to digital logic. The earliest digital computers were special purpose devices, designed as automatic calculators to solve specific problems, e.g. calculating missile trajectories. At the time, to interact with the computer system, the user requires knowledge of a thorough understanding of the electronic design to utilize electrical circuits for programming the machine, such as the Small-Scale Experimental Machine, *Baby*, built by Williams and Kilburn in 1948.

b) Symbolic

After electrical HCIs came symbolic ones. The primary form of programs, i.e. the machine language, moved from a numeric form to other symbolic forms that were comparatively more understandable to human beings than the electrical HCI. It presented a set of symbolic representations of computer system operation as the primary modality by which interaction was conducted. Meanwhile, this was also reflected in the physical interaction with systems. Punch cards served as a primitive form of symbolic interaction for both data cards (cards that carried information for programs to process) and control cards (guiding the system to initiate and terminate tasks, etc.).

c) Textual

One of the best forms of symbolic HCI is written language and textual interaction. Textual interaction allows us to have a "dialog" with computers by applying our own linguistic skills. People can create meaningful sentences by combining characters into words and sets of words as elements for human-computer communications.

d) Graphical

The transition from textual to graphical interaction is one of the most significant evolutions in HCI. Visually speaking, graphical interaction turns interaction from a one-dimensional stream of characters into a two-dimensional space. Also, graphical interaction exploits further areas of human ability as part of the interactive experience as follows:

- ***Peripheral Attention***
  Information distributed into a two-dimensional array allows us to arrange it in different areas based on the importance. For instance, many applications divide the screen (the window) into two areas: a large area that hosts the main interaction while the smaller one displays the current progress of other tasks or ancillary information.

- ***Pattern Recognition and Spatial Reasoning***
  Organizing information graphically provides opportunities to arrange data spatially. It merges our experience of navigating in the physical world into a virtual one. Humans have the ability to recognize patterns in the special organization of information. Consequently, it provides new ways to transfer information and assemble data elements as one entity.

- ***Information Density***
  "A picture really can be worth a thousand words." Some information can be conveyed in a more efficient and understandable graphical format than textual one. The scope of interaction is enlarged to incorporate graphical and textual presentation forms simultaneously.

- ***Visual Metaphors***
  The graphical approach of HCI can add value by applying visual metaphors for conveying and perceiving information with computers. The most common examples are

mimicking our daily working environments in the office, e.g. desktop tools, file cabinets, trash cans, etc.

e) Embodied

As Dourish states the idea of a "computer reaching out" in 2004, computation moves beyond the traditional confines of the desk and attempts to incorporate itself more richly into our daily experience of the physical and social world. Embodiment is about the fact that things are embedded in the world, and the ways in which their reality depends on being embedded. Embodied HCI involves two concepts: tangible computing and social computing.

- ***Tangible Computing***
  Tangible computing encompasses a number of different activities, distributing computation across a variety of devices, which are spread throughout the physical environment and are sensitive to their location and proximity to other devices. Tangible computing explores how to enable the computer to get "out of the way" and provide people with a much more direct, tangible interaction experience.

- ***Social Computing***
  Social computing attempts to explore how the interaction between users and computers can be seen as similar and dissimilar to the way in which humans socially interact every day. Besides, social computing also explores how the single-user HCI can be enhanced by incorporating information and the related social activities.

Embodied HCI builds on the phenomenological understandings to create a foundational approach to embodied interaction, serving as the core element that tangible and social computing rely on. Besides, from the development of HCI that Dourish states, embodied HCI is the most direct and intuitive way that allows the user to interact with technologies. The user need not be fully versed in specialized computation skills, e.g. programming, but can interact with computers intuitively. Accordingly, embodied HCI can be applied as design criteria for intelligent home care environments since the target audience will be the elderly, people who normally do not have abundant experience, understanding or comfort interacting with computers. The next section will explore tangible computing in terms of tangible user interfaces.

6) A Tangible Approach of Human-Computer Interaction: Tangible User Interfaces

The Xerox Star workstation introduced the first generation of GUI (Graphical User Interface) in 1981, formulating a "desktop metaphor" which simulates a desktop on a bit-mapped screen. However, the interactions between people and cyberspace are largely confined to traditional GUI-based interfaces placed on desktops or laptops, e.g. monitors. The interactions with these GUIs are detached from the ordinary physical environment.

To bridge the gaps between the physical environment and cyberspace, as well as the foreground and background of human activities, the concept of Tangible User Interfaces (TUIs) is proposed by Hiroshi Ishii at the MIT Media Laboratory (Tangible Media Group), allowing users to "grasp and manipulate" bits in the center of users' attention by combining the bits with everyday physical objects and architectural surfaces. Besides, TUI also enables users to be aware of background bits at the periphery of human perception using ambient display media, e.g. light, sound, airflow, and water movement in an augmented space.

The main objectives of TUIs could be summarized as follows:

a) ***Coupling of Bits and Atoms***: Seamless coupling of everyday graspable objects with the digital information that is associated. The graspable objects might be books, cups, tools, etc., that anything accessible in our daily life.
b) ***Interactive Surfaces***: Transformation of each surface within architectural space (e.g., walls, desktops, ceilings, doors, windows) into an active interface between the physical and virtual worlds.
c) ***Ambient Media*****:** Except the foreground activities of human-computer interaction, e.g. a user typing on a computer at a desk, TUIs also propose to apply ambient media (e.g. airflow, sound, light, etc.) as background interfaces, allowing the user to interact with cyberspace through various kinds of human sensorium.

Stimulated by ubiquitous computation, TUIs intend to awaken richly-afforded physical objects, instruments, surfaces, and spaces to computational mediation, borrowing more from the physical forms of the pre-computer age than the present. In brief, TUIs are exploring different methods to apply various types of physical matter (e.g. solid, liquid, and gases matter) that exist in the physical environments as "interfaces" between people and digital information.

6.3.3 Interface Design of Intelligent Home Care Environments

Based on the cross-disciplinary discourses regarding the aforementioned theories of human-environmental interaction, this section explores interface design criteria for the proposed Intelligent Home Care Environments (IHCEs), as well as how these design criteria can benefit the elderly.

1) Increase Human Sensorium—Ambient Media and Calm Technology

Human sensory apparatus are essential receptors for interacting with the environments (Hall, 1966; Rapoport, 1990b). From Lawton's theory, as people age, their perceptional receptors slowly lose functions they were accustomed to. According to Actor-Network Theory and Non-representational Theory, people's sensory perception could be extended with the assistance of technologies (Latour, 2007; Thrift, 2007). Technology is beneficial for bridging the gap between individuals and the environment caused by functional limitation [21] (Verbrugge & Jette, 1994).

In Human Computer Interaction, people live in the world with central awareness and peripheral[22] awareness (Weiser, 1995). Ambient Media is an approach that conveys information

[21] In the Disablement Model, functional limitation is a part of disablement process. It is defined as restrictions in basic physical and mental actions, e.g. ambulate, research, grasp, speak, hear, etc. (Verbrugge & Jette, 1994).
[22] Periphery is defined as what we are attuned to without attending to explicitly (Weiser, 1995).

via calm changes (Calm technology) in the environment so that users are more able to focus on their primary tasks while staying aware of non-critical but important information that affects them (Pousman & Stasko, 2006). Calm Technology engages both the center (Foreground activities) and the periphery (background activities) of our attention, and moves back and forth between the two (Buxton, 1997). For instance, a man talking on the phone (the foreground activity) may be aware of the sound of rain outside (the background activity).

Applying Ambient Media and Calm Technology as an interface design can help extend human sensorium and enable people to better interact with their environments. From the viewpoint of gerontology, Ambient Media can help the elderly keep in touch with their friends or family and increase their cognitive functioning by keeping them socially engaged for a successful aging[23]. For example, a digital flower vase capable of sensing movement in the house and encoding that physical movement into a digital signal. The signal can be transmitted and received remotely through the Internet. Once a digital vessel receives a signal transmitted from another vessel, it emits soft light accordingly. Imagine two 65-year sisters (Nancy and Amy) living separately in their own houses. They are moderately concerned with each other's status yet wish to maintain a certain degree of privacy and prefer not to unnecessarily disturb the other with incessant telephone calls. Each has a digital vase her living room. If Nancy is ambulatory and moving around her house, her vase signals the information to the one in Amy's house, which then emits light. Through the digital vessels, each sister is aware of the others' movement through an unobtrusive ambient way. By knowing that a family member is doing something in their own house, it relieves the burden of repeated direct contact such as twice a day telephone calls. Meanwhile, this ambient media enables Nancy and Amy to be socially connected while maintaining a certain degree of personal privacy. Meanwhile, this calm technology can be applied for tracking a user's status to assure that the user is still moving around in the house but without showing exact location, preserving a certain degree of individual privacy. This example will be applied in *Section 7.3* as a part of Scenario 05.

2) Increase the Sense of Belonging— Manipulating Objects that Support Personal Taste

As Rapoport states, people need to bring objects, especially movable objects to participate and bring meaning to their environments, increasing their sense of belonging (Rapoport, 1990b). From Taste Theory, objects themselves and how they are assembled represent personal taste as well (Cranz, 2004). A physical environment that supports individual taste can satisfy the user's psychological needs through personal identity.

In HCI design, the physical object that is used to access digital information is required to reflect the nature of the digital information it is associated with (Holmquist, Redström, & Ljungstrand). For instance, imagine a few photo frames affixed to the wall aside a 70 year-old man's bed. Each photo comprises a series of images and carries precious memories of his family and friends. Touching each photo frame enables the series of images to be projected on the ceiling, allowing the user to lie on the bed and enjoy them. Once specifically thinking of any of these friends or family, he can easily make a phone call or send a greeting message to the person simply by rearranging the photo frame closer to the pillow on the bed.

---

[23] From the viewpoint of gerontology, successful aging requires three attributes: 1) Low risk of disease and disease-related disability, 2) High mental and physical function, and 3) Active engagement with life (especially socially engaged) (Rowe & Kahn, 1997).

In this interface design, the input object (the photo frame) has a symbolic feature while also representing the user's personal taste. Meanwhile, the interaction with the interface increases the user's sense of belonging to the environment, and depicts his natural behavior (Kaptelinin & Nardi, 2006): when the user thinks of someone in the photo, he usually rearranges the photo frame closer to the pillow so that he can see it more clearly while lying on the bed.

3) Encourage Physical Activities and Multiple Posture—Tangible User Interface Design and Body Conscious Design

From view point of Body Conscious Design and Lawton's environmental theory, a well-designed environment should support multiple postures (postural pluralism) and encourage kinetic activities (Cranz, 2000). Regarding Human-Computer Interaction (HCI), Nicholas Negroponte mentions that rendering bits into human-readable form has been restricted mostly to displays and keyboards. Although people have five senses24, their connection to computers is "sensory deprived and physically limited." By contrast, "tangible bits" allow us to interact with them with our muscles as well as our minds and memory (Ishii & Ullmer, 1997; Moggridge, 2007).

"*Hands bring us knowledge of the world. They are the most subtle, sensitive, probing, differentiated, and the most closely connected to the mind. By pointing, by pushing and pulling, by picking up tools, hands act as conduits through which we extend our will to the world (McCullough 1999).*"

-by McCullough, 1996

Tangible User Interface (TUI) design is a new approach of HCI that bridges the gap between digital bits and atoms (Ishii & Ullmer, 1997). Meanwhile, TUI allows and encourages the user to access digital information with physical activities. Through the interacting process of TUIs, people can make good "use" of their physical bodies (complementing the Alexander Technique); instead of sitting or positioning themselves statically and manipulating conventional interfaces, such as keyboards and button controllers.

From the view point of Activity Theory25, interface design is a process of human activity design, not just tools (Kaptelinin & Nardi, 2006). Attempts to incorporate human activity into interaction design have led to ideas of "activity-based," "activity-centered," or "activity-centric" computing. Accordingly, the interface design should encourage people to use their physical activities and multiple postures to interact with their environments.

[24] From view point of body-mind and body workers, people have more than five senses, e.g. being able to use hands for feeling (Cranz, 1990).

[25] Activity Theory aims to understand individual human beings, as well as the social entities they compose, in their natural everyday life circumstances, through an analysis of the genesis, structure, and processes of their activities. It comprises three elements: subjects (people), tools (mediators), and objects (motivations)((Kaptelinin & Nardi, 2006).

For instance, home care-oriented interfaces should benefit the patient's well-being based on their body condition and body consciousness. Imagine a 65-year-old woman living alone suffering from serious back problems. To help her easily access more facilities in the environment, the system might integrate many operations into the living room sofa. The system would allow her to manipulate some objects, such as opening a window or turning on a television by operating a switch embedded in the sofa. Nevertheless, this might have significant drawbacks—the woman might become more sedentary, which could aggravate her back problems. From the viewpoint of Body-Conscious Design, there is no perfect static sitting posture. The best sitting posture is always the next one (Cranz, 2010). The system must balance the demands of the woman's convenience with those of her health issues for optimization. Consequently, the sofa might become a dynamic interface providing multiple sitting postures, and assisting the user through a range of motions, enabling her to control objects in a healthier way.

4) Conclusion of Interface Design for IHCEs

Lawton's theory explores the dynamic relationship between environmental press and personal competence. The ability of people to adapt to the environment changes, especially as they age. At the same time, the environment has a limited ability to support an occupant's activities. Having too much or too little environmental press could cause negative impacts on the individuals, such as behavioral disabilities (Verbrugge & Jette, 1994) or cognitive helplessness (Peterson et al., 1993; Seligman, 1975).

Regarding the social-cultural perspective of environmental design, Burno Latour and Nigel Thrift shed light on the social network between people, objects, and the environment. Instead of treating environments as static, limited space containing "environmental press," Actor-Network Theory and Non-representational Theory advocate that human-environmental interaction is a dynamic, unlimited, continuous movement that can be amplified by technologies. In addition, Taste Theory provides a way of observing and evaluating the physical environments from the activity and the outcome of people's taste, i.e. how pragmatic and symbolic objects are assembled aesthetically. Different from the standpoint of traditional psychologists, Body Conscious Design proposes the concept of "body-mind" that cognition is also a form of perception. From the viewpoint of BCD, an environment should well support multiple postures and encourage people to "use" their bodies in multiple postures—postural pluralism (Cranz, 2000). An Eastern philosophy of Acupuncture Theory provides another perspective with which to consider human-environmental interaction—a holistic, systematic approach. It elaborates how energy (Qi) flows and keeps balance between the human body (microcosm) and the environments (macrocosm) through the cooperation of multiple subsystems, e.g. energy channels, five phases, and biological systems. Acupuncture Theory contains several characteristics such as 1) the dynamic hierarchy and 2) dynamic grouping/ control scope that can be applied as a model for human-environmental design, e.g. the intelligent environment.

Drawing from the aforementioned theory comparisons, a good interface design should be able to assist dynamic relationships between people, places, and objects (Buchenau & Suri, 2000). It should enable the user to access the physical realm easily and appropriately (the balance of environmental press and individual competence), encourage body movement and postural pluralism, and endow the process of human-environmental interaction with specific social and cultural meanings, e.g. personal taste. Through the assistance of technologies, human sensorium can be amplified and bridged (when people are aging) in order to facilitate and maintain a positive human-environmental interrelationship.

6.4 Conclusion

The proposed Intelligent Home Care Environment (IHCE) comprises a computational system and physical environmental design. Applying Acupuncture Theory as a metaphor endows the design of Dynamic Multi-Agent System (DMAS) with the following benefits: 1) multiple subsystems and the dynamic hierarchy, 2) dynamic grouping and control scope, and 3) the ability of optimization among safety, resource efficiency, and adaptability. To research how human-computer interfaces should be designed in IHCE to best benefit senior citizens, the various theories regarding human-computer interaction are reviewed from different disciplines, including the epidemiology of aging (Lawton's Press-Competence Model), sociology (Actor-Network Theory and Non-representational Theory), social/ cultural factors (Taste Theory), body-mind consciousness (Body Conscious Design), and Human-Computer Interaction (Tangible User Interface). Meanwhile, from the perspective of human-environmental interaction, built environments are designed with limited affordance to support certain activities. The user has limited ability for adaptation, especially as they age (Lawton & Nahemow, 1973). By applying technologies appropriately, the user's sensorium could be increased to scaffold the decreased ability of adapting the physical environment caused by the process of aging, allowing the elderly to live independently, yet retain a good quality of life. Through manipulating objects with embedded technologies at home, the user can have a strong sense of belonging to the physical environment (Rapoport, 1990b), and interact with technologies more intuitively. Tangible User Interfaces allow the elderly to interact with IHCE with their muscles as well as minds and memory (Ishii & Ullmer, 1997; Moggridge, 2007) without requiring specific skills for Human-Computer Interaction (HCI), e.g. typing commands or manipulating complicated machines. By applying Body Conscious Design as the interface design criteria for IHCE, seniors are encouraged to increase the amount of physical activity they undertake, e.g. performing stretching their body, having multiple postures while interacting with the smart space. The user can make good "use" of their body benefiting their physical self.

Chapter VII

System Testing and Evaluation Using Scenarios

The proposed Intelligent Home Care Environment (IHCE) comprises computational systems, smart appliances, and human-computer interfaces that require abundant financial and human resources to construct physically. Due to a limited budget and time, this research formulates a hypothetical prototype of an IHCE for system testing and evaluation with different scenarios for external validity testing prior to investing in physical construction. These scenarios include the assistance for the elderly in physical/ cognitive functioning, code blue monitoring, and a multiple activity scenario. As discussed in *Section 5.4*, the subjects included in the scenarios are representative personas derived from a database created through the Healthy Aging Network Walking Studies (HANS)(William A. Satariano et al., 2010). The study included 884 people aged ≥ 65 years identified through service organizations in four different locales (Alameda County CA, Cook County IL, Allegheny County PA, and Wake and Durham Counties NC) in the United States. Each type of samples (personas) represents a portion of subjects enrolled in the HANS, and has different levels of physical/ cognitive functioning, requiring different health care assistance. The list of testing scenarios and the assistance of IHCE is as follows (Table 32):

Scenario Objective	Scenario Number	IHCE Assistance
Reactive/ Proactive assistance in Activities of Daily Living (ADL)/ Instrumental Activities of Daily Living (IADL)	Scenario 01	▪ Dressing ▪ Housework (Laundry) ▪ Bathing/ Showering
	Scenario 02	▪ Meal Preparation ▪ Physical functioning (has trouble of stooping, crouching or kneeling)
Safety Issues (Code Blue)	Scenario 03	▪ Medication ▪ Fall Monitoring
	Scenario 04	▪ Suspicious Events Monitoring

Multiple Activity Scenario Evaluation	Scenario 05	▪ Nyctalopia (night blindness) ▪ Has trouble of getting up from a deep bend, crouching or kneeling position ▪ Traveling ▪ Financial management ▪ Shopping ▪ Depression ▪ Medication ▪ Social Network ▪ Health monitoring (sitting posture)

Table 32 The overview of scenarios

This research adapts a trial-and-error method, utilizing different scenarios to test the proposed IHCE system and examine the efficacy of Dynamic Multi-Agent Systems (DMAS) on a step by step basis for external validity, revising DMAS back and forth accordingly. The scenarios aim to examine IHCE from four separate perspectives: 1) the ability to assist the elderly with physical and cognitive functioning re-actively and proactively, and 2) the ability of providing optimized assistance in home care based on the core tenets of achieving the utmost level possible of safety, resource efficiency, and adaptability, 3) the ability to demonstrate different characteristics of intelligent agents, and 4) the ability to support the user's personal tastes as derived from social and cultural perspectives. Accordingly, five categories of design criteria developed in *Section 4.2.3* are applied for evaluating the proposed IHCE. Each scenario comprises two perspectives: the user's activity (events) and IHCE's protocols (system responses), and each is documented chronologically by numbers (no.1, 2. 3, etc.). The contents of the various scenarios cover details of the interaction between the elderly and the IHCE, including computation systems (DMAS and sub-systems), smart appliances, and Human-Computer Interfaces (HCIs). Most of the computational systems and smart appliances/ HCIs are original to this research yet could be created and implemented in the near future, while some technologies are currently available (Table 33). Details of the technologies will be illustrated and applied in the different scenarios.

Origins of Technologies / Categories of Technologies	Proposed Technology	Developing Technology	Available Technology	Scenario number
Computational systems (subsystems)	The Smart Laundry System			Scenario 01
	The Smart Laundry Center			Scenario 01
		The Smart Dressing System,(by *Living 3.0*, Taipei, Taiwan, 2012)		Scenario 02

	Fall Monitoring System			Scenario 03
	Suspicious Events Monitoring System			Scenario 04
			The Indoor GPS System (by *Living 3.0*, Taipei, Taiwan, 2012)	Scenario 04
	Posture Monitoring System			Scenario 05
Smart Appliances/ HCIs	The e-Live Wall			Scenario 01, Scenario 02
			The Interactive Wall (by *Intel*, 2010)	Scenario 01, Scenario 02
	The e-Laundry Closet			Scenario 01
			The Smart Woven Labels (by *Quality Woven Labels*, NY, 2013)	Scenario 02
	The Smart Dressing Closet			Scenario 02
	The Smart Cabinet			Scenario 02
	The Smart Refrigerator			Scenario 02
	The Smart Oven			Scenario 02
		LED Lighting System (by *UC-Light, University of California*, 2009)		Scenario 03
	The Smart Drink Machine			Scenario 03
	The Smart Sofa			Scenario 05
	The e-Flower Vase			Scenario 05

Table 33 Types of computational systems and smart appliances/ HCIs in the scenarios.

Each scenario comprises two components: 1) a system diagram that illustrates how each agent within the Dynamic Multi-Agent System functions, including system protocols and the communication hierarchy among different Intelligent Agents (IAs), and 2) a table illustrating details of events chronologically by numbers (e.g. No.1, 2, 3, etc.). Each table of scenarios is delineated from two perspectives: 1) the user's activity (events) and 2) the IHCE's protocols (system responses). Each event on the table is associated with the number in the system diagram chronologically as the red dash line shown in Fig. 28.

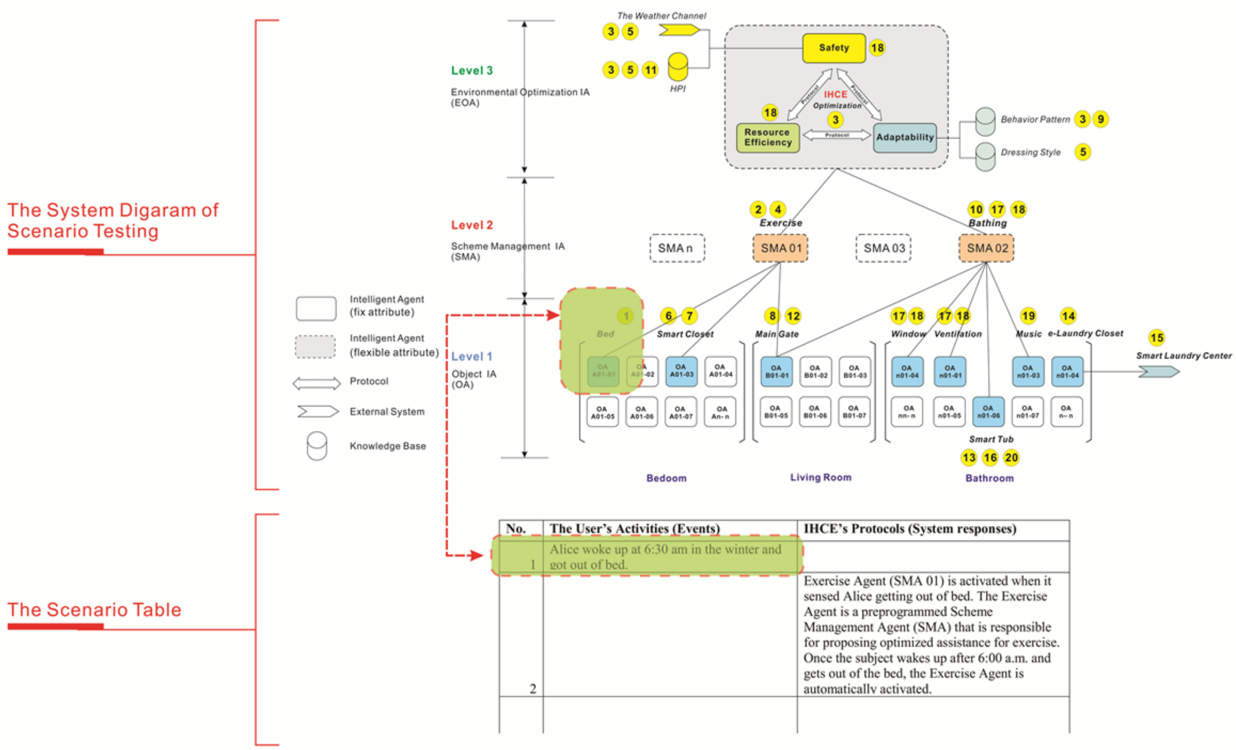


Fig. 28 The diagram explaining how the system diagram is associated with the scenario table to demonstrate system testing with scenarios chronologically.

7.1 Reactive/ Proactive assistance in Activities of Daily Living (ADL)/ Instrumental Activities of Daily Living (IADL)

This section focuses on illustrating responses of Intelligent Home Care Environments (IHCE) regarding reactive and proactive assistance in ADL and IADL, specifically concerning dressing, bathing, housework (doing laundry), and meal preparation.

A. The Subject Profile

Scenario 01/ 02		
Sample Type	Type 01	
Name	Alice	
Age	75	
Gender	Female	
Subject's Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	▪ has Coronary Heart Disease	Not included
	▪ has Hypertension	
	▪ has Osteoporosis	

	▪ has trouble bending over, crouching or kneeling	52.95
	▪ has trouble getting up from a stooping, crouching or kneeling position	63.76
Cognitive Functioning	▪ Percentage reporting one or more memory errors (Number of correct responses--recall three objects few minutes later)	48.36
	▪ has problems with memory (self-assessment)	7.01
	▪ has trouble concentrating ▪ (self-assessment)	3.64
System Assistance		Subjects who require assistance in HANS (%)
Activities of Daily Living (ADL)	▪ Dressing	0.79
	▪ Bathing/ showering	4.53
Instrumental Activities of Daily Living (IADL)	▪ Housework (Laundry)	Not included
	▪ Meal Preparation	
	▪ Shopping	

Table 34 The subject profile of Scenario 01 and 02

B. Human-Environmental Interface and Smart Appliance Design

To perceive and interact with the physical world, the proposed Intelligent Home Care Environment (IHCE) includes various human-environmental interfaces and smart appliances that serve as end-agents (object agents) allowing the subject to interact with and control, up to a point, the automated features of the home. Each scenario involves different interfaces and different appliances responsible for different tasks.

- **The e-Live Wall**

  The e-Live Wall is an integrated interface that functions as an overall control panel for information management and provides a user display. It combines functions of communication (e.g. managing e-mails), real-time information (e.g. tracking weather forecasts, the latest television or radio shows, etc.), a house self-monitoring system (e.g. energy consumption, current temperature, air quality, etc.), and Internet access. The e-Live Wall contains a large touch screen that can be manipulated by the user and display messages accordingly. It can also interact directly with the user through voice-controls to perform certain tasks including verbally reading e-mails and confirming decisions audibly with the user (Fig. 29).

Fig. 29 Intel Infoscape Multi-touch Wall (Darren Murph, 2010)

- **The Smart Woven Labels**

For the automated system to manage and care for the user's garments, each piece of clothing has a woven QR Code[26] that contains information regarding its material and composition, laundry directions, brand, manufacturing company/origin, and the owner's contact information (Fig. 30, 31).

Fig. 30 Woven QR Code designed by Trekky (Trekky, 2011).

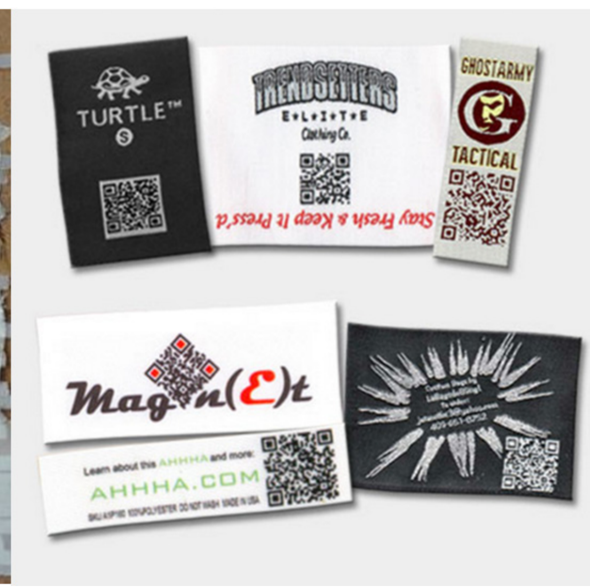


Fig. 31 Smart Woven Labels by *Quality Woven Labels,* NY (Woven Quality Labels, 2013).

[26] Invented by Denso Wave, QR Code (abbreviated from Quick Response Code) is the trademark for a type of matrix barcode (or two-dimensional code) first designed for the automotive industry. The code consists of black modules arranged in a square pattern on a white background. The information encoded can be made up of four standardized kinds ("modes") of data (numeric, alphanumeric, byte/binary, Kanji), or through supported extensions, virtually any kind of data. QR Code comprises six features as follows: 1) high capacity encoding of data, 2) small printout size, 3) Kanji and Kana capability, 4) dirt and damage resistant, 5) readable from any direction in 360°, and 6) structured appending feature (QR code.com, 2013).

- **The Smart Laundry System**

The system comprises three distinct entities: the e-Laundry Closet, the Smart Laundry Center, and the Smart Dressing Closet. Once the user places dirty clothes into the e-Laundry Closet, essentially a special hamper in the bathroom, these clothes are delivered to Smart Laundry Center for cleaning through an automated trolley system. After being appropriately laundered, the clothes will be delivered back to the Smart Closet in the bedroom by caregivers (Fig. 32).

Fig. 32 The Smart Laundry System

- **The e-Laundry Closet**

This appliance is located in the bathroom. It collects dirty clothes and delivers them to the Smart Laundry Center via an automated trolley system. When dirty clothes are placed in the closet, the e-Laundry Closet is activated through several embedded sensors that transmit a notification ping to the Smart Laundry Center, instructing it to commence operations. To enhance safety, the signal can only be transmitted after the user closes the closet door.

- **The Smart Laundry Center**

The Smart Laundry Center is an external system that processes the clothes for all of the units within the apartment building or assisted living facility. Ideally, each Smart Laundry Center serves around 100-150 apartments in the community. The Smart Laundry Center is located within the same building. All of the clothes deposited into the Smart Laundry Center are sorted automatically using the woven QR code, grouped with items needing the same care (e.g., cold wash, gentle cycle, dry clean, line dry) and delivered to different departments to clean. After receiving the clothes, the Smart Laundry Center will generate an electronic receipt for each item containing the owner's contact information, the updated status for processing, and expected time of delivery back to the owner by an automated trolley system.

- **The Smart Dressing Closet**

The Smart Dressing Closet can cooperate with Adaptability Agent to reference the user's sense of style and cross-reference those with the predicted weather and whatever social activities are planned. Meanwhile, the Smart Dressing Closet can connect to the Virtual Dressing Club for exchanging, renting, or purchasing different clothes (Fig. 33).

Fig. 33 The Smart Dressing System, Living 3.0, Taipei, Taiwan, 2012.

- **The Smart Cabinet**

To assist subjects who have difficulty stooping over, crouching down, kneeling, or lifting their arms, The Smart Cabinet comprises movable inner sections that automatically adjust up and down. By pressing the number of the inner section on the control panel, the chosen inner section will be moved to a height that allows the subject to access the objects easily. It also helps subjects unable to lift or carry heavy items.

- **The Smart Refrigerator**

Each unit of food/ material can be sensed and categorized by the smart refrigerator using the bar codes printed on external packaging for the following information: nutrition facts, directions for preparation, ingredients, manufacturing date, expiry date, price, brand, and manufacturing company/origin. The Smart Refrigerator contains a touch screen on the door showing the status of all of the food inside, various recipes for preparing meals or dishes from the ingredients on hand, and enabling user interaction. When the user places an order via the touch screen, The Smart Refrigerator will connect to the Internet and find an online store(s) providing the requested item. Meanwhile, The Smart Refrigerator also compares various prices and calculates the total cost including shipping charges and notes the projected delivery dates among various different online merchants (Fig. 34).

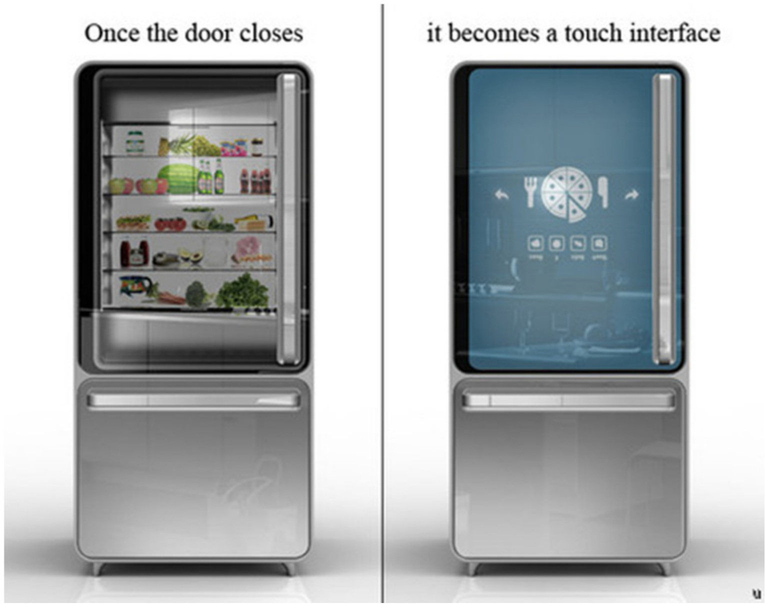


Fig. 34 The Conceptual Smart Refrigerator (Kee, 2010)

- **The Smart Oven**

The Smart Oven is an intelligent appliance that assists the user in safely cooking and appropriately heating the food, and is especially helpful for users who have difficulty preparing meals for themselves, e.g. those suffering from significant memory loss that are unable to complete a given recipe. This appliance is connected to The Smart Refrigerator and enables the transfer of food from the refrigerator to the oven. The user can prepare meals by themselves or with the assistance of the e-Live Wall which will display the recipe and step by step instructions. Once prepared, the dish is automatically transferred to the Smart Oven. Through sensors, the Smart Oven differentiates between different foods by recognizing bar codes printed on external packaging. By accessing its database of ingredients, recipes and directions for the preparation of different foods, the Smart Oven can adjust its own heat and cooking time to prepare different types of food appropriately.

C. Scenario 01: Dressing/ Bathing/ Laundry

This scenario demonstrates how IHCE assists the elderly regarding Activities of Daily Living (dressing/ bathing) and Instrumental Activities of Daily Living (laundry) (Fig. 35, Table 35).

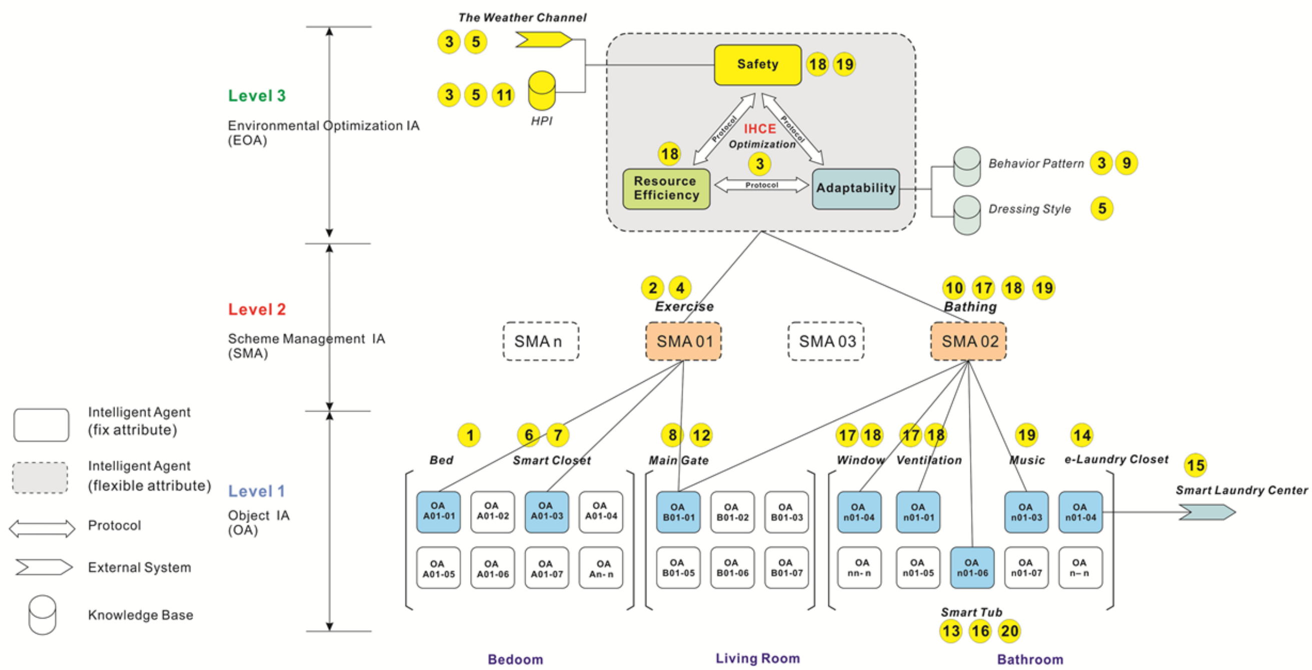
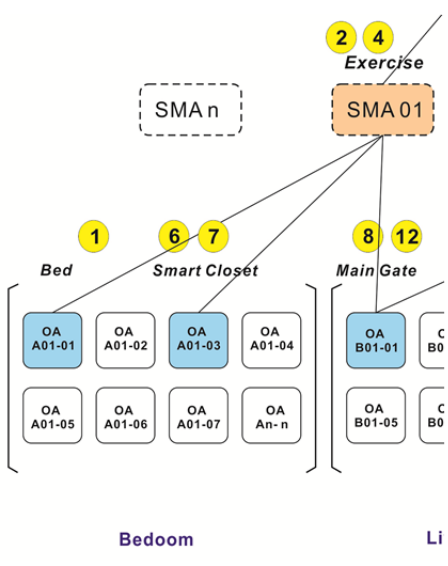
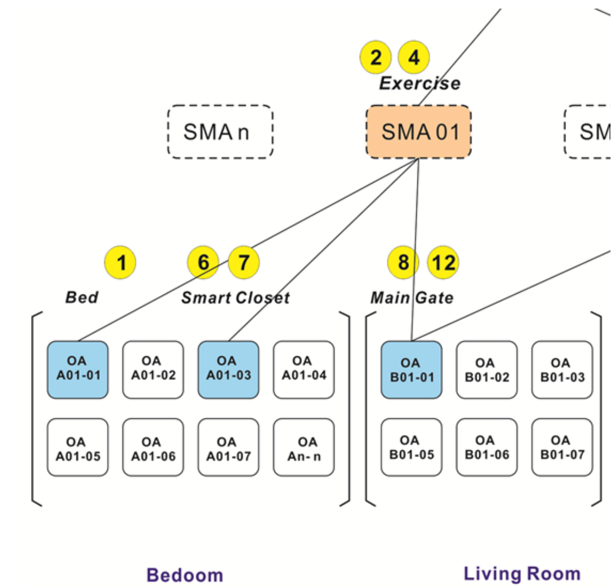
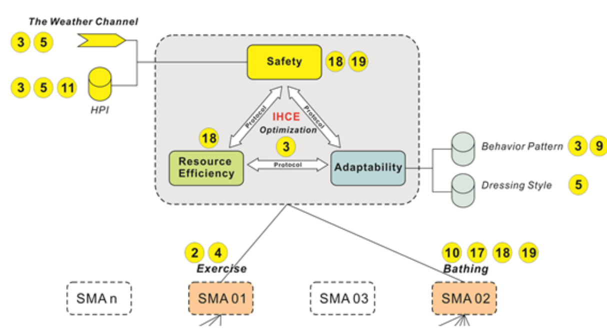
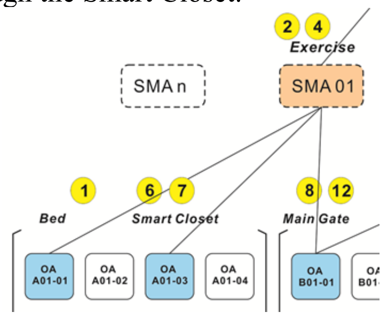
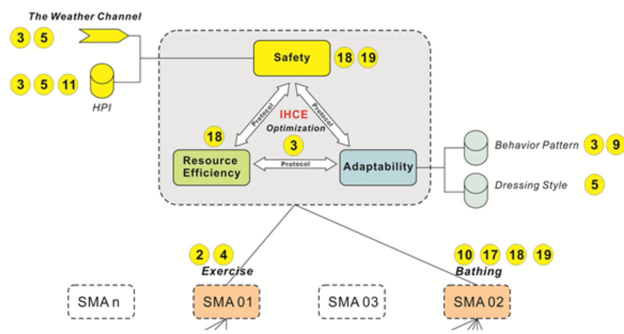
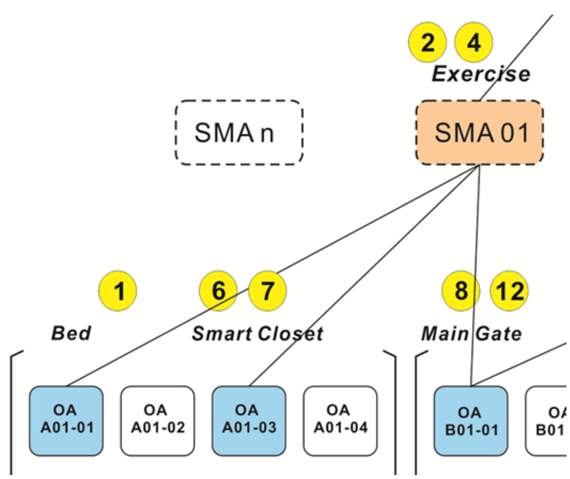


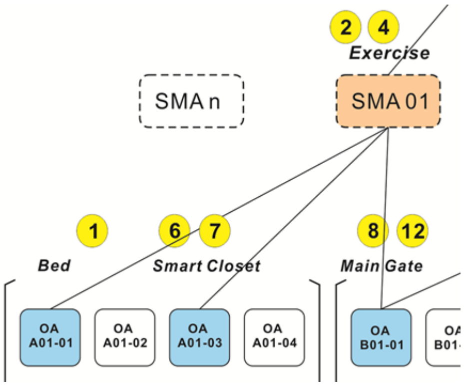
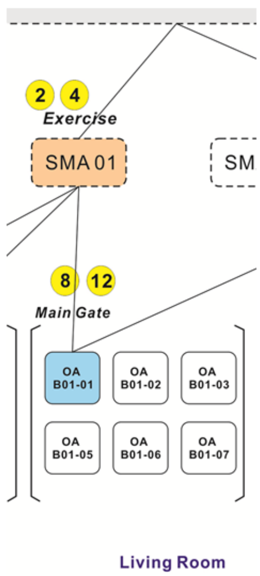
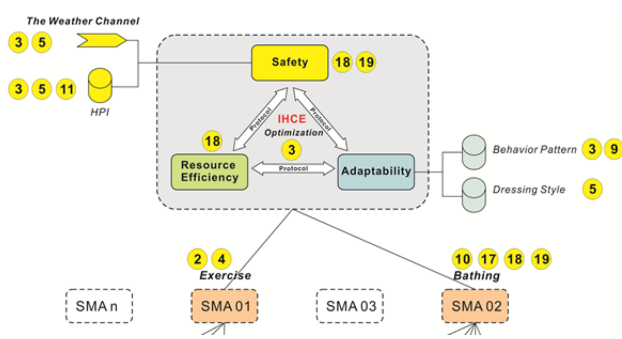
Fig. 35 The diagram of system testing for Scenario 01

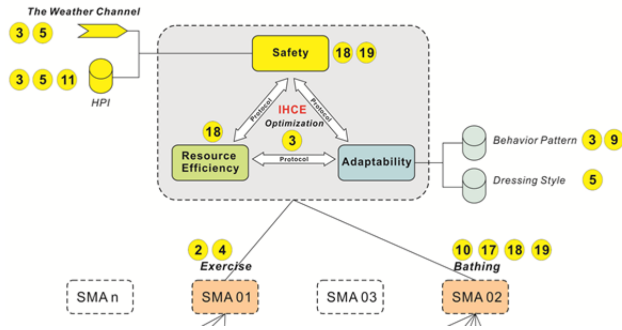
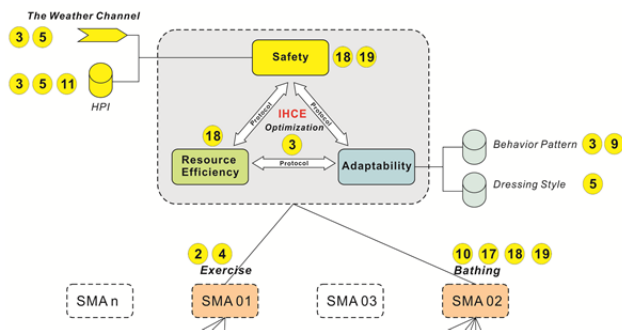
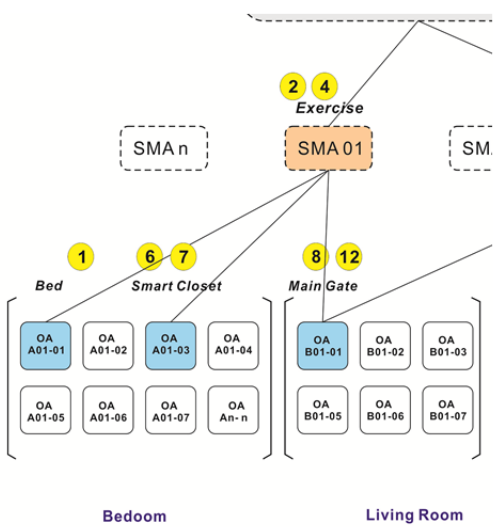
To help understand how the scenario is tested in the Dynamic Multi-Agent System of IHCE step by step, the scenario table 01 contains both texts and the corresponded area of the system diagram. In considering the length of the document, the other scenario tables (Scenario 02-05) contain only texts to save space.

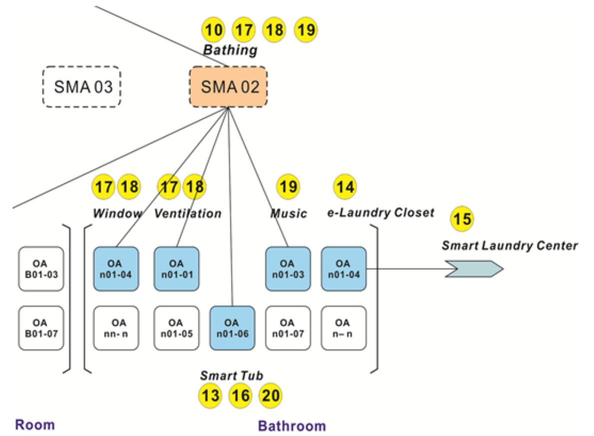
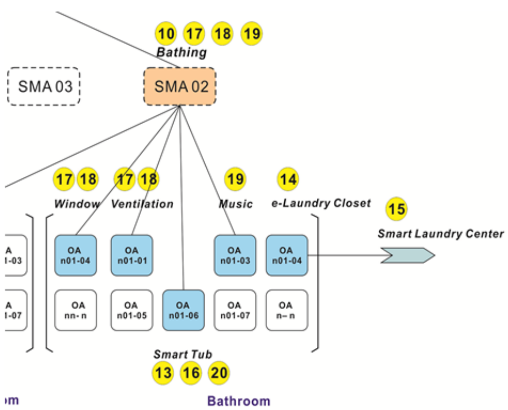
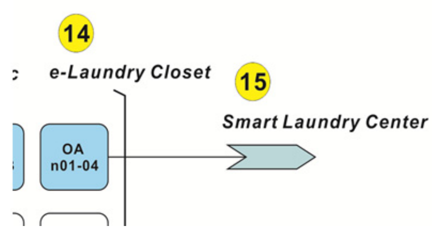
No.	The User's Activities (Events)	IHCE's Protocols (System responses)
1	Alice woke up at 6:30 am in the winter and got out of bed. 	

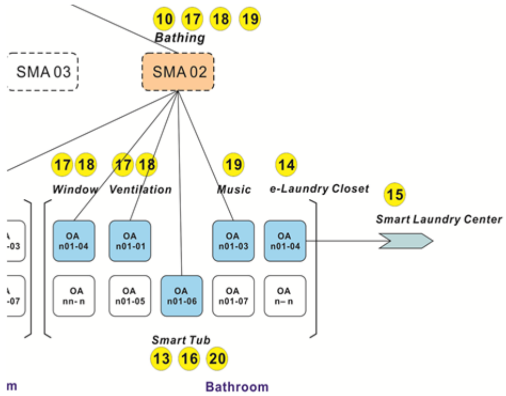
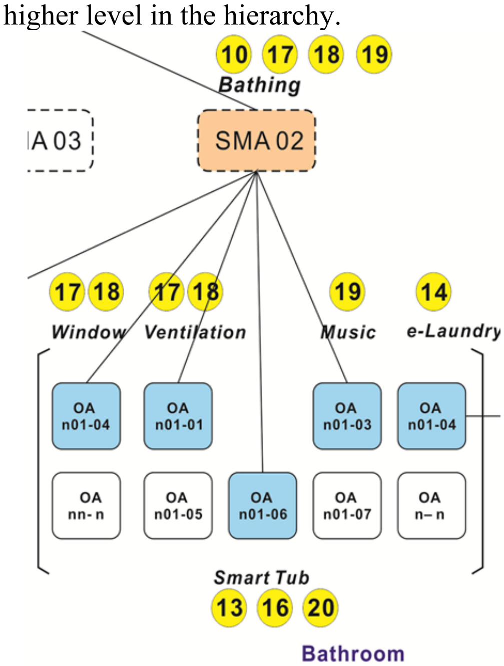
2		Exercise Agent (SMA 01) is activated when it sensed Alice getting out of bed. The Exercise Agent is a preprogrammed Scheme Management Agent (SMA) that is responsible for proposing optimized assistance for exercise. Once the subject wakes up after 6:00 a.m. and gets out of the bed, the Exercise Agent is automatically activated. 
3		After consulting Safety Agent and Adaptability Agent regarding current weather conditions and exercises currently recommended by her physician or physical therapist, the Exercise Agent suggests that Alice consider taking a walk. 

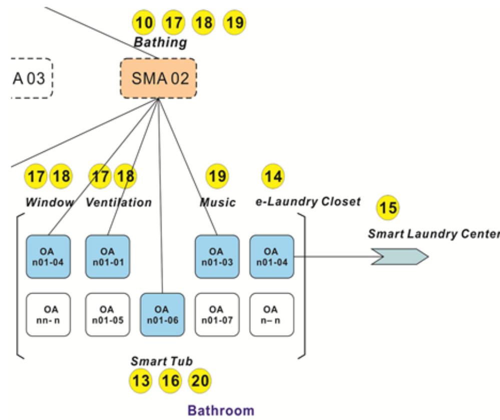
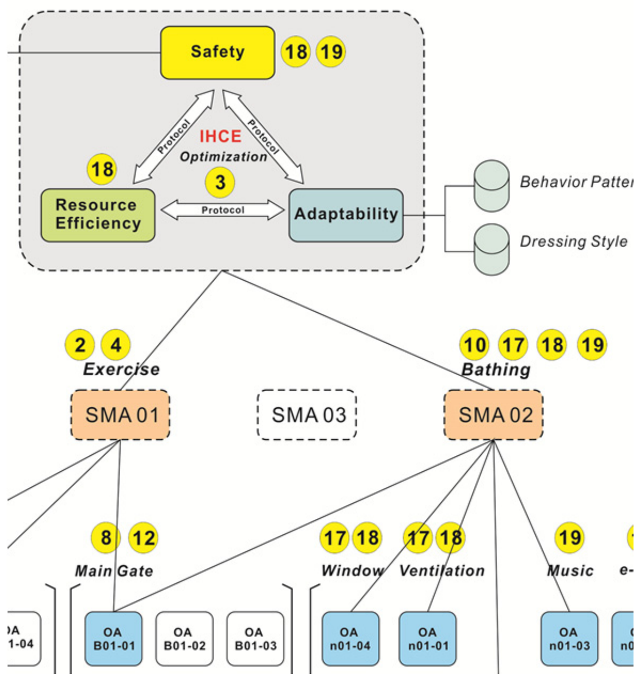
4	Alice decided to walk in the neighborhood for exercise and requested IHCE to suggest appropriate clothes through the Smart Closet. 	
5		Exercise Agent consults Safety Agent, Resource Efficiency Agent, and Adaptability Agent for an optimized solution regarding appropriate clothes that are suitable for Alice's health, the planned activity, personal taste and current weather conditions. 
6		Exercise Agent manages the Smart Closet to show the suggested outfit. 

<table>
<tr>
<td>7</td>
<td>Alice retrieved the suggested clothes from the Smart Closet.

</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Alice left her house though the main entrance for her walk.

</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Exercise Agent consults Adaptability Agent regarding Alice's behavior pattern and shows that she enjoys a hot rosewater bath after a walk on a brisk winter morning.

</td>
</tr>
</table>

<table>
<tr>
<td>10</td>
<td></td>
<td>IHCE activates Bathing Agent (SMA 02) for the preparation of a hot bath.

</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Bathing Agent consults the Safety Agent and is instructed as to the appropriate water temperature and bathing period based on Alice's HPI.

</td>
</tr>
<tr>
<td>12</td>
<td>After walking, Alice returned to her house.

</td>
<td></td>
</tr>
</table>

13		Bathing Agent coordinates the Smart Tub Agent for preparing water at an appropriate temperature with rose scent and monitors the length of Alice's bath. 
14	Alice walked into the bathroom and placed her dirty clothes in the e-Laundry Closet. 	
15		The e-Laundry Closet senses the dirty clothes and delivers them to the Smart Laundry Center by an automated trolley system. 

16	Alice started taking a hot tub in the bathroom. 	
17		After 10 minutes, the Window Agent in the bathroom senses an elevated level of moisture and opens the window in the bathroom for ventilation. Meanwhile, the Ventilation Agent also senses high humidity and would like to turn on mechanical ventilation. The conflict between two object agents triggers intervention by the Bathing Agent, which is at a higher level in the hierarchy. 
18		After consulting Resource Efficiency Agent and Safety Agent, Bathing Agent learns that opening the window in the bathroom in the winter might lead to a cold draft, harmful to people with coronary heart disease. Thus, the Bathing Agent directs the Ventilation Agent to turn on mechanical ventilation, leaving the window opened only slightly for fresh air.

<table>
<tr><td></td><td></td><td>
</td></tr>
<tr><td>19</td><td></td><td>Since Alice has coronary heart disease and hypertension, after 15 minutes of bathing the, Safety Agent manages Bathing Agent to play music (the Music Agent), reminding Alice to finish her bath within 5 minutes.

</td></tr>
</table>

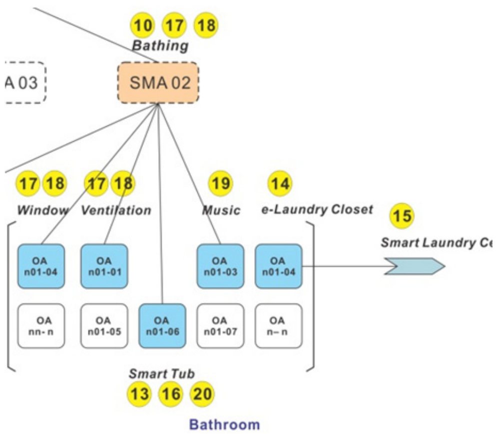
20	Alice finished her bath and leaves the bathroom. 	

Table 35 The Scenario 01: Dressing/ Bathing/ Laundry

D. Scenario 02: Meal Preparation

This scenario demonstrates how IHCE assists the elderly regarding IADL (meal preparation) (Fig. 36, Table 36).

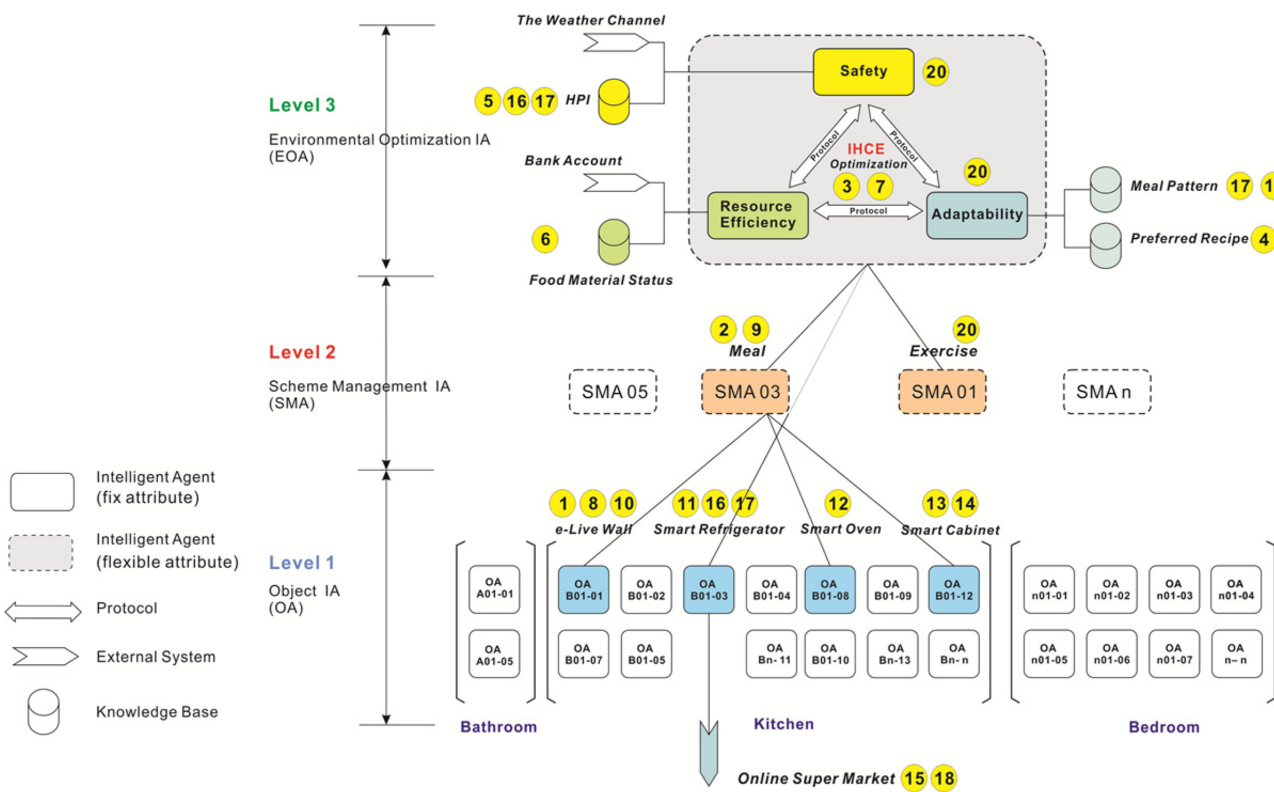


Fig. 36 The diagram of system testing for Scenario 02

No.	The User's Activities (Events)	IHCE's Protocols (System responses)
1	Alice was preparing dinner in the evening and asked IHCE for assistance on the e-Live Wall.	
2		IHCE formulates Meal Agent in response to Alice's request.
3		Meal Agent consults IHCE for an optimized solution.
4		Adaptability Agent checks Alice's preferred recipe.
5		Safety Agent checks Alice's HPI.
6		Resource Efficiency Agent checks database reported by the Smart Refrigerator regarding the status of materials in the refrigerator, knowing that some materials are going to expire soon and should be consumed within the next few days.
7		IHCE suggests Alice an optimized recipe that both fits her preference and is appropriate for her health and uses food items already on hand.
8	Alice accepted the suggested recipe.	
9		IHCE manages Meal Agent to assist Alice step by step.
10		Meal Agent manages Smart Refrigerator to show the recipe on e-Live Wall and reads it verbally step by step.
11	Each ingredient that Alice uses has a QR code on its external packaging that includes cooking methods. Once Alice takes the ingredients out of the external package, all she has to do is to place them into the right kitchen appliance, e.g. the Smart Oven, based on the instruction, and place the QR code close enough to the equipment for it to be read.	
12		The smart appliance reads the QR code and will control the process, e.g. the strength of the heat, cooking duration, etc.
13	Alice would like to take required seasoning and plates from the cabinet, yet she has back problems and has difficulty stooping down far enough or kneeling to get the objects from the lower partition of the cabinet.	
14		Meal Agent manages the Smart Cabinet, directing it to move the inner partitions up and down so that the required objects are available to Alice without having to bend or kneel down.

15	Besides, Alice has recently been suffering from mild depression and requests certain “comfort foods” from an online super market such as a slice of cake and fried chicken--food that contains excessive sugar and calories.	
16		Smart Refrigerator checks Alice’s HPI and suggests a low calorie sugarless cake.
17		After checking Alice’s meal pattern and HPI, Smart Refrigerator offers a warning message, reminding Alice that she has had fried chicken twice this week and that she should avoid a third portion this week.
18	Alice accepted the suggested sugarless cake as an adequate substitution and cancels the order of fried chicken.	
19		Smart Refrigerator integrates Alice’s meal list to her meal pattern for her doctors’ future review.
20		IHCE coordinates Exercise Agent to reconfigure Alice’s exercise schedule for additional physical exercise (Yoga) to compensate for the consumption of extra calories.

Table 36 The Scenario 02: Meal Preparation

7.2 Safety Issues (Code Blue)

Since safety is seen as the top priority in home care, this scenario concerns safety issues regarding how IHCE can respond to an emergency (code blue), including the monitoring system detecting a fall and other suspicious events.

7.2.1 Fall Monitoring

A. The Subject Profile

Scenario 03		
Sample Type	Type 02	
Name	Kevin	
Age	85	
Gender	Male	
Subject’s Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	▪ has difficulty maintaining balance	13.99

	▪ Suffered a serious fall within the previous two years	18.79
Cognitive Functioning	▪ Percentage reporting two or more memory errors (Number of correct responses: recall three objects few minutes later)	58.90
	▪ has problems with memory ▪ (self-assessment)	7.01
	▪ has trouble concentrating ▪ (self-assessment)	3.64
System Assistance		
	▪ Medication ▪ Fall Monitoring	

Table 37 The subject profile of Scenario 03

B. Human-Environmental Interface and Smart Appliance Design

▪ Lighting System

This research applies UC Light project as lighting systems. UC Light proposes using LEDs as interfaces for both lighting and communication (transmitting and receiving signals.) Each LED has a sensor and is responsive within a 5' in diameter sensing area. Once the user steps into the sensing area, the LED turns itself on, receiving and transmitting signals interactively (Fig. 37).

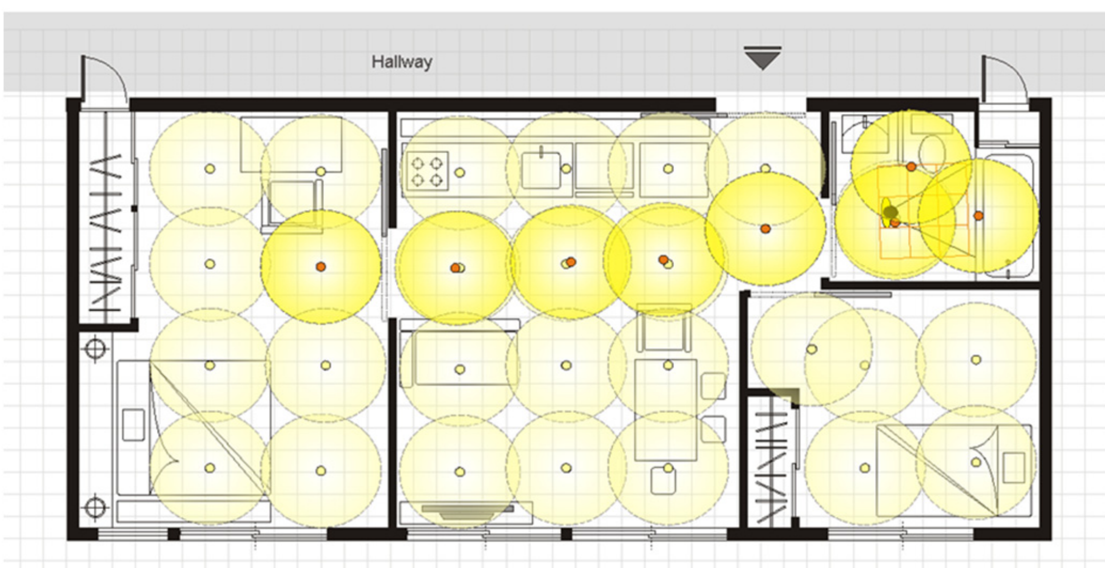


Fig. 37 LED Lighting system

- **Indoor GPS System**

This research applies Radio-Frequency Identification (RFID) technology for identifying the user's indoor location. RFID is a wireless, contact-free system that utilizes radio-frequency electromagnetic fields for transmitting data from a tag attached to an object, for the purpose of automatic identification and tracking. When wearing a RFID tag, the user can be sensed and identified by their location in the house automatically. It helps IHCE identify whether the user is moving, how long they have remained at the same spot, or whether their behavior pattern has changed by comparing current behavior with recorded norms.

- **Smart Drink Machine**

This appliance is responsible for managing various types of drinks for the user and simplifying the process of preparing various beverages, including tea, coffee, milk, juice, etc. The directions for making different drinks are preprogrammed. Ingredients are stored either in the machine itself or in the Smart Refrigerator. By manipulating the touch screen on the machine, or even controlling the machine through voice control, the user can enjoy various drinks easily without having to remember or perform complicated processes to make a drink themselves. It can also decrease the possibility of being injured by overly hot water when making a hot drink.

- **Fall Monitoring System**

Falling is perhaps one of the most serious issues in aging. IHCE provides a Fall Monitoring System that can respond immediately, by calling for help as soon as possible. The blue squares represent individual floor sensors that can sense instant force. By using the formula, $F = mg$, the system will generate an indicator number by using the user's weight. Once the floor senses any instant force close to this indicator number (± 3 Newton), it will cooperate with the Indoor GPS Agent to check the movement of the user, in case an item of similar weight to the user toppled, such as a piece of furniture, preventing a false alarm.

If the user doesn't move for more than 30 seconds, IHCE will assume that a fall has occurred, that an emergency exists and automatically call for help (Fig. 38).

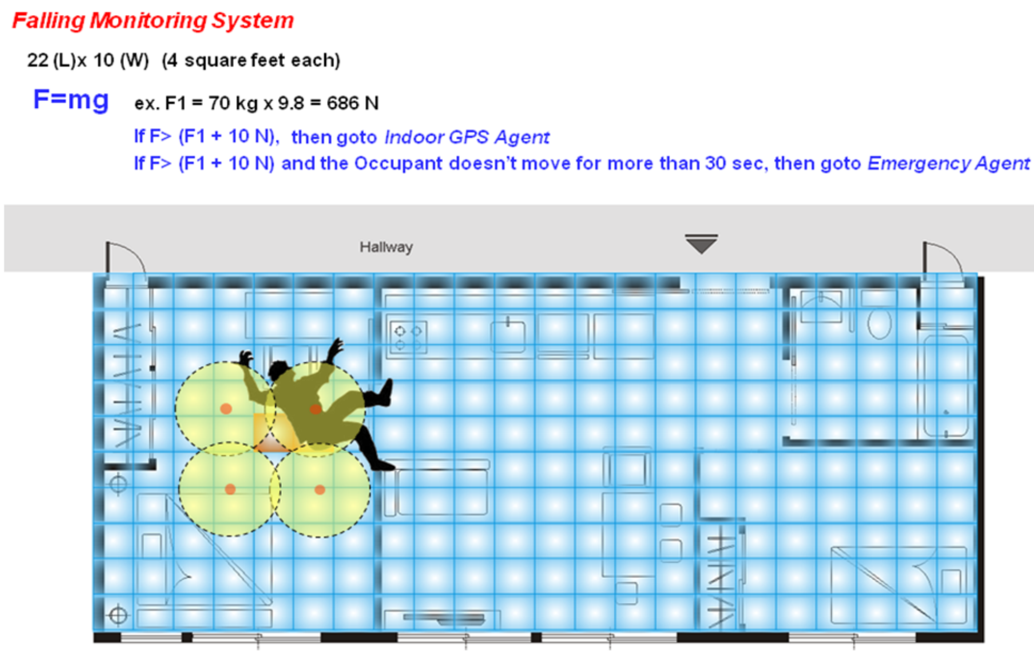


Fig. 38 Falling Monitoring System

C. Scenario 03: Fall Monitoring

This scenario demonstrates how IHCE monitors suspicious events in home care and responses accordingly (Fig. 39, Table 38).

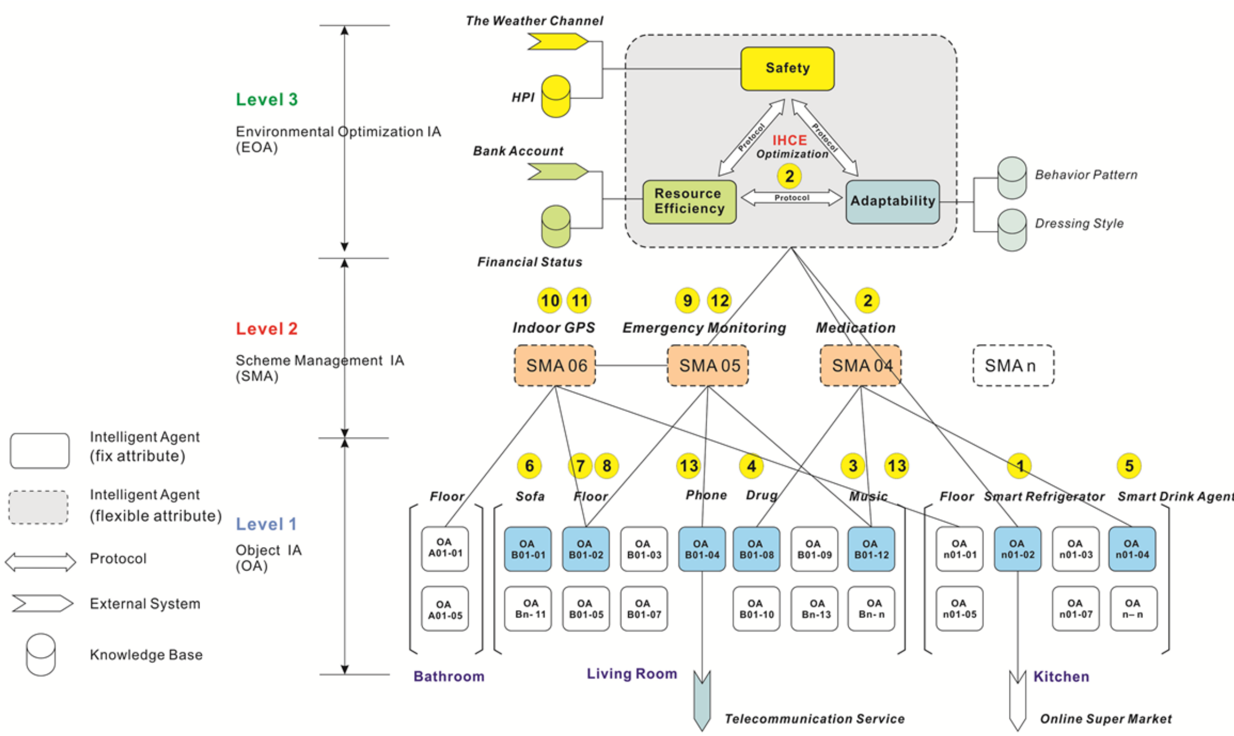


Fig. 39 The diagram of system testing for Scenario 03

No	The User's Activities (Events)	IHCE's Protocols (System responses) System Execution
1	Kevin finished breakfast in the kitchen at 8:00 a.m.	
2		After 30 minutes, IHCE coordinates Medication Agent (SMA 04) to remind Kevin for medication. Medication Agent is a preprogrammed scheme management agent that can assist the subject in taking medicine on schedule with accurate dose.
3		Medication Agent coordinates Music Agent to play music to remind Kevin for medication.
4		Medication Agent coordinates with the Drug Agent to prepare an accurate dose of medication.
5		Medication Agent coordinates Smart Drink Agent for preparing warm water.
6	Kevin heard the Music Agent's alert tone, and got up from the sofa to take his medicine.	
7	Suddenly, Kevin lost his balance and falls down on the floor.	
8		Floor Agent senses an instant force corresponding with the indicator number associated with Kevin's weight.
9		Floor Agent transmits this data to Emergency Monitoring Agent (SMA 05).
10		Emergency Monitoring Agent cooperates with Indoor GPS Agent (SMA 06) to locate Kevin's location and movement.
11		Indoor GPS Agent establishes that 30 seconds have elapsed between when the Floor Agent sensed the instant force, and yet, no additional movement is detected. The Indoor GPS Agent determines that Kevin has been in the same spot for more than 30 seconds.
12		Emergency Monitor Agent assumes that a fall might have occurred.
13		Emergency Monitor Agent coordinates several object agents for emergency: 1) Coordinate Phone Agent for calling 911 and Kevin's family/ friends. 2) Coordinate Music Agent for playing alarm to call for help from any available neighbors.

Table 38 The Scenario 03: Fall monitoring

7.2.2 Suspicious Events Monitoring

This scenario demonstrates how IHCE monitors suspicious events in home care and responses accordingly (Fig. 40, Table 39, 40).

A. The Subject Profile

Scenario 04		
Sample Type	Type 03	
Name	Nancy	
Age	80	
Gender	Female	
Subject's Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	▪ low functionality of vision (nyctalopia)	Not included
	▪ has difficulty getting up from a stooping, crouching or kneeling position	63.76
Cognitive Functioning	▪ Percentage reporting one or more memory errors (Number of correct responses: recall three objects a few minutes later)	48.36
	▪ has problems with memory ▪ (self-assessment)	7.01
	▪ has trouble concentrating ▪ (self-assessment)	3.64
System Assistance		
	▪ Suspicious Events Monitoring	

Table 39 The subject profile of Scenario 04

B. Scenario 04: Suspicious Events Monitoring

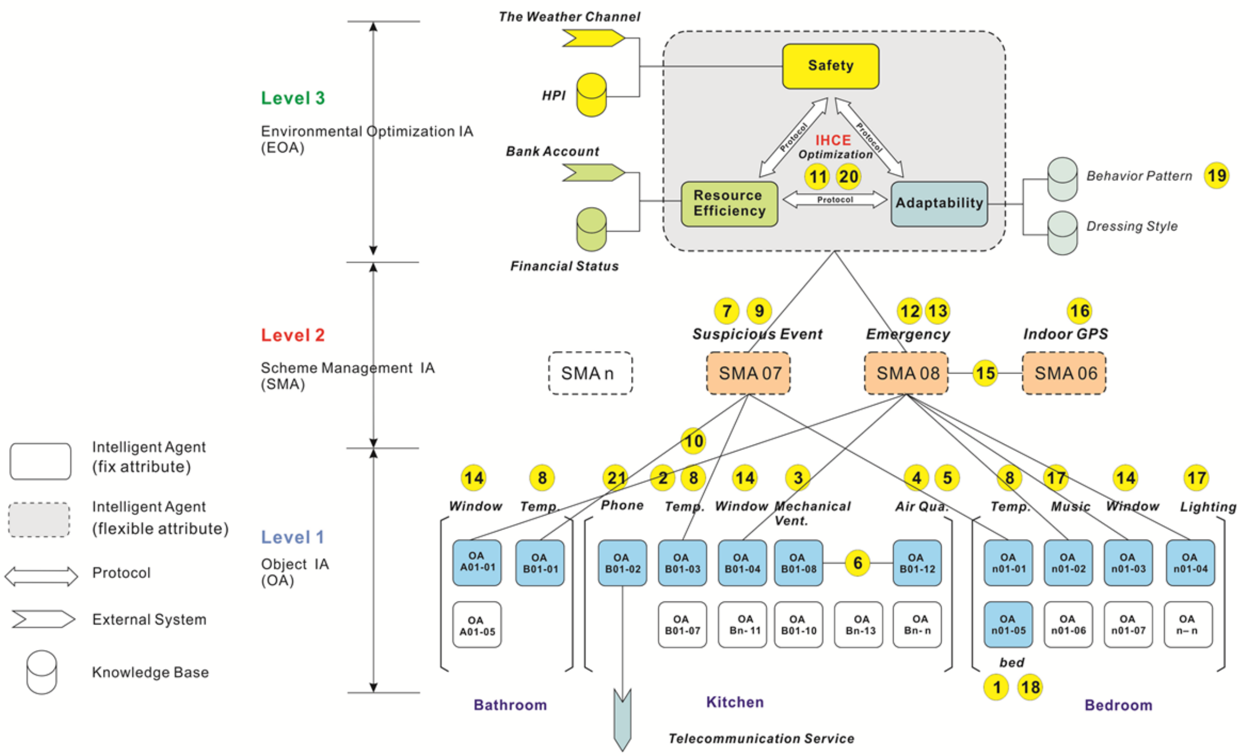


Fig. 40 The diagram of system testing for Scenario 04

No	The User's Activities (Events)	IHCE's Protocols (System responses) System Execution
1	After cooking lunch, Nancy forgot to entirely turn off the gas in the kitchen. Feeling sleepy, she decided to take a nap in the bedroom at 1:30 pm.	
2		At 4:30pm, the Temperature Agent in the kitchen detects that the temperature is higher than the standard value.
3		The Mechanical Ventilation Agent in the kitchen would normally activate various electric devices to reduce the indoor temperature.
4		However, the Air Quality Agent detects that CO in the kitchen is simultaneously excessive.
5		Air Quality Agent would normally turn off all electric devices in the kitchen.
6		A Conflict between The Mechanical Ventilation Agent and the Air Quality Agent occurs, activating the IHCE for mediation and intervention.

7		IHCE formulates Suspicious Event Agent (SMA 07) to investigate the incident.
8		Suspicious Event Agent coordinates different Temperature Agents in the kitchen, the living room, and the bedroom for comparison.
9		Suspicious Event Agent detects unusual temperature differences: the temperature in the kitchen is 10 degrees higher than in the bedroom and living room, and 15 degrees higher than the current outdoor temperature.
10		Meanwhile, the Temperature Agent in the kitchen senses that the temperature keeps increasing at a rate exceeding 5℃ every 15 minutes.
11		Suspicious Event Agent transmits all of the data back to IHCE for making system assumptions: 1) Some appliances in the kitchen might be faulty 2) There might be a gas leak 3) The occupant might be in danger
12		IHCE formulates Emergency Agent (SMA 08) in reflect to the suspicious event.
13		Emergency Agent cuts off electricity in the kitchen.
14		Instead of turning on any mechanical ventilation appliances that could trigger an explosion due to a possible gas leak, the Emergency Agent coordinates Window Agents to open all the windows in the house.
15		The Emergency Agent cooperates with the Indoor GPS Agent to check the user's location as well as movement status.
16		The Indoor GPS Agent finds that the user has remained in the bedroom without moving for more than 30 seconds.
17		Emergency Agent manages Music Agent to ring alarms and Lighting Agent to flash light to alert and awaken Nancy.
18	Nancy failed to respond to the alarm or exhibited any movement.	
19		Emergency Agent consults Adaptability Agent to check the user's current behavior pattern. Adaptability Agent indicates that Nancy usually moves around in the living room or kitchen after 3:00 pm.
20		IHCE System Assumptions: The occupant may have fainted or lost consciousness.

21		IHCE manages Emergency Agent to call for help: 1) Coordinate Phone Agent to call 911, the building manager, the user's neighbors, and family members/ friends. 2) Continue to try to awaken Nancy by ringing alarms and flashing lights unceasingly.

Table 40 The Scenario 04: Suspicious Events Monitoring

7.3 Multiple Activity Scenario Evaluation

This is a multiple activity scenario demonstrating an example of how IHCE can assist the elderly within a day (from midnight till the afternoon). This multiple activity scenario involves a compilation of various types of the subject's characteristics (Table 41) and required assistance, e.g. deficiency of lower-body functioning and cognitive functioning.

A. The Subject Profile

Scenario 05		
Sample Type	Type 04	
Name	Grace	
Age	85	
Gender	Female	
Subject's Characteristics		Subjects who have the symptom in HANS (%)
Physical Functioning	▪ low functionality of vision (nyctalopia)	Not included
	▪ has difficulty of getting up from a stooping, crouching or kneeling position	63.76
	▪ has difficulty pushing moderately heavy objects such as a living room chair	31.78
	▪ has difficulty seeing because of the glare from sun or indoor lights	16.78
	▪ has difficulty sitting for periods of an hour or more	22.58
	▪ has difficulty of standing up after sitting in a chair	37.08
Cognitive Functioning	▪ Depression	15.29
	▪ has Problems with memory (self-assessment)	7.01
	▪ has Trouble concentrating (self-assessment)	3.64

System Assistance		Subjects who require assistance in HANS (%)
Activities of Daily Living (ADL)	▪ Transferring	1.13
	▪ Walk across a room (Visual Direction)	6.00
Instrumental Activities of Daily Living (IADL)	▪ Traveling	Not included
	▪ Financial Management	
	▪ Online Shopping	
	▪ Medication	
	▪ Social Network (call for help)	
Others	▪ Pulse and blood pressure measurement	Not included
	▪ Lighting Control	Not included
	▪ Health monitoring (sitting posture)	
Family Member/ Friends (friends or relatives live around/ people the subject feels at ease with, can talk to about private matters and can call on for help)	Veronica (daughter)	97.51

Table 41 The subject profile of Scenario 05

B. Human-Environmental Interface and Smart Appliance Design

- **Smart Sofa**

The Smart Sofa is a piece of furniture that enables the user to control different objects in the house through controls embedded in the back of the furniture. By using the design criteria from Body Conscious Design and Tangible User Interface Design, the main idea of the Smart Sofa is to allow the user to control electronic appliances, e.g. a television, intuitively with their body while at the same time encouraging body movement. When manipulating the controls, the user receives the mild benefit of changing their sitting position, helping prevent back and spinal problems associated with long periods of remaining in the same position. Meanwhile, the Smart Sofa can also assist the user in standing up by gradually raising its sitting surface from the seat back toward the front. It helps users who have difficulty standing up after sitting in a chair or sitting for long periods, e.g. one hour (Fig. 41).

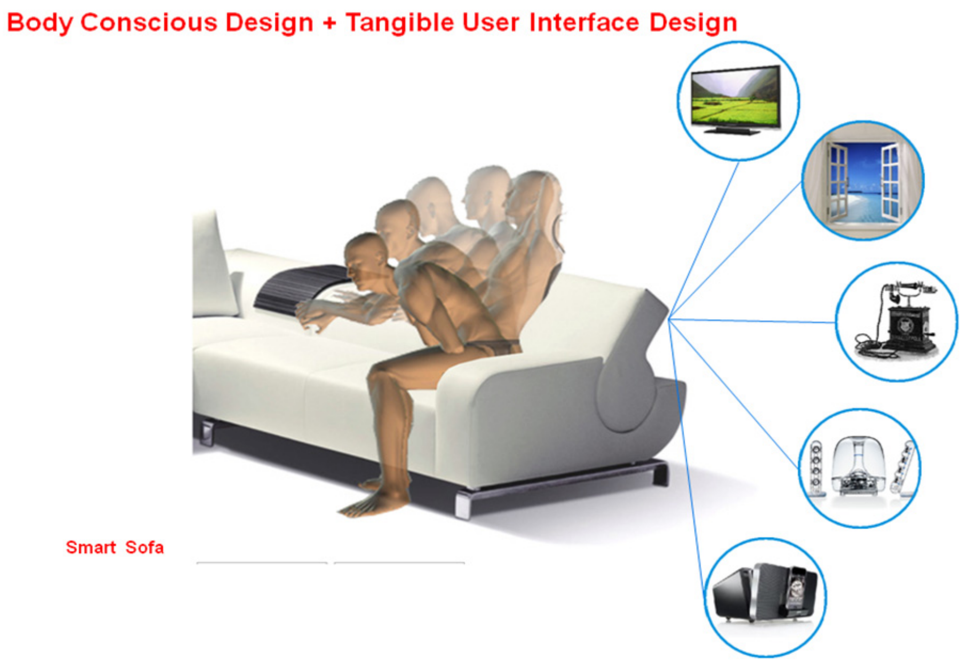


Fig. 41 The conceptual diagram of Smart Sofa

- **The e-Flower Vase**

The e-Flower Vase is an electronic device that can sense movement in the house and encode the physical movement into a digital signal. The signal can be received and transmitted remotely through the Internet. Once a digital vessel receives a signal transmitted from another vessel, it emits soft light and fragrance accordingly. Imagine two sisters (Alice and Nancy) living separately in their own houses. They are each concerned with their sister's well-being yet they both wish to maintain a certain degree of privacy. Each has a digital vase in her living room. If Nancy is ambulatory and moving around her house, her vase signals the information to the one in Alice's house, which then emits light. Through the digital vessels, each sister is aware of their sibling's movement via an unobtrusive ambient way. By knowing that a family member is doing something in their own house, it relieves the burden of repeated direct contact such as twice-a-day telephone calls. Meanwhile, this ambient media enables Nancy and Alice to be socially connected while maintaining a certain degree of personal privacy.

C. Scenario 05: Multiple Activity Scenario

This section is divided into three portions in terms of different periods a day: midnight (scenario no. 1-28) (Fig. 42, Table 42), morning (scenario no. 29-42) (Fig. 43, Table 43), and afternoon (scenario no.43-55) (Fig. 44, Table 44). Each portion contains scenario descriptions and system responses.

1) Portion A: No. 1-28

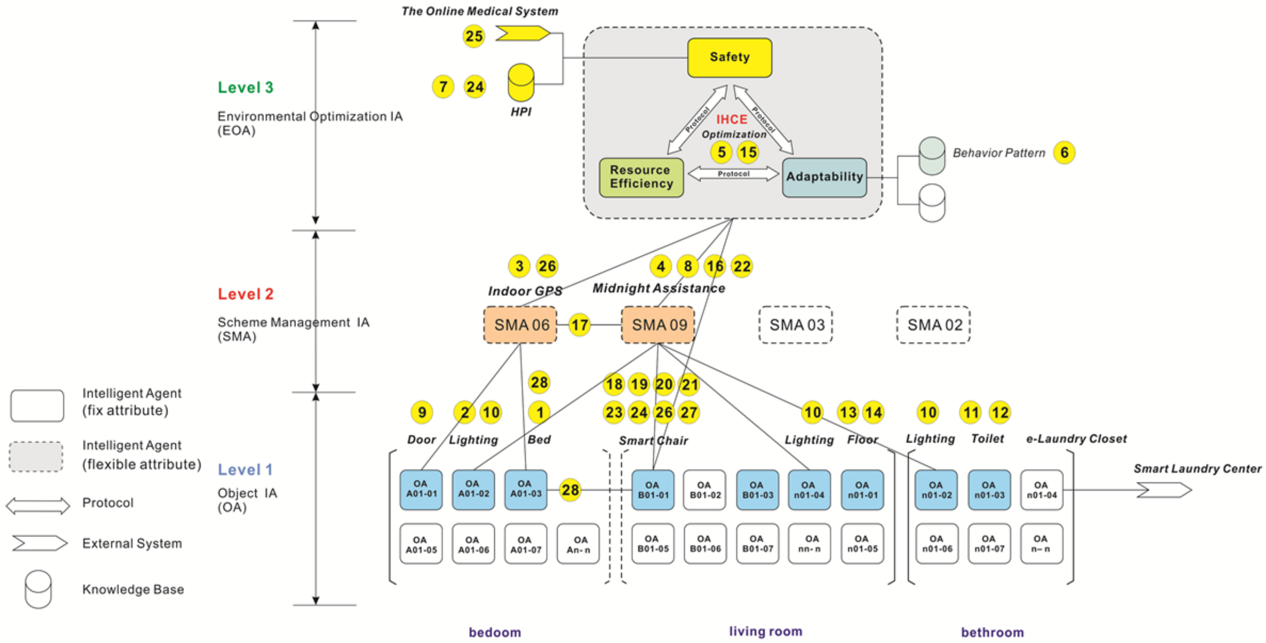


Fig. 42 The diagram of system testing for Scenario 05 (Portion A)

No.	The User's Activities (Events)	IHCE's Protocols (System responses)
1	Grace woke up and got out of the bed at 2:00 a.m.	
2		Lighting in the bedroom senses Grace's movement and is turned on.
3		Indoor GPS System (SMA 06) is informed about Grace's movement and sends this information to IHCE.
4		IHCE formulates Midnight Assistance Agent (SMA 09) to assist Grace. Midnight Assistance Agent is a pre-programmed Scheme Management Agent that is responsible for proposing optimized assistance for Grace in the middle of the night. Once Grace wakes up and starts to move around the house, the Midnight Assistance Agent is automatically launched.
5		The Midnight Assistance Agent consults the Safety Agent and the Adaptability Agent to provide optimized assistance to Grace in the middle of the night.
6		The Adaptability Agent references Grace's behavior patterns and knows that 85% of the times that Grace wakes up during the night, it is to use the bathroom.

7		The Safety Agent checks Grace's HPI and knows that Grace has low vision functionality, especially during late night hours.
8		IHCE instructs the Midnight Assistance Agent to provide optimized assistance especially tailored for Grace at night: visual lighting assistance.
9	Grace walked from the bed to the bedroom door.	
10		Since Grace has vision issues, the Midnight Assistance Agent manages all lighting agents in the bathroom and on the way from the bedroom to the bathroom and turns on all the lights at once.
11	Grace walked to the bathroom.	
12	Grace finished using the bathroom.	
13	When returning to the bedroom, Grace dropped her sleeping cap on the floor in the living room.	
14	Grace knelt down to pick up the cap, but was unable to get up from kneeling.	
15	Grace asked IHCE for assistance by saying the key phase, "help stand up."	
16		IHCE manages the Midnight Assistance Agent for assistance.
17		Midnight Assistance Agent coordinates Indoor GPS Agent to locate Grace's position.
18		The Midnight Assistance Agent coordinates Smart Chair to move within Grace's reach.
19	Grace held on to the back of the Smart Chair, and asked the Smart Chair to rise.	
20		The back of the Smart Chair gradually rises, helping Grace stand up.
21	With the assistance of IHCE, Grace returned to an upright position.	
22		Midnight Assistance Agent recommends that Grace sit down on the Smart Chair for a brief rest.
23	Grace accepted the system recommendation and sat on the Smart Chair.	
24		Smart Chair measures Grace's blood pressure and pulse, sending data back to Safety Agent for comparison. IHCE notices that Grace's blood pressure is higher than standard and deduces that she might feel dizzy.
25		The Smart Chair reminds Grace about her physical condition and sends a notice to her doctor through the online medical system.

26		The Midnight Assistance Agent coordinates with the Indoor GPS Agent and the Smart Chair, sending Grace back to the bed by moving Smart Chair with Grace sitting on it.
27		Smart Chair adjusts its sitting height to equilibrium with the bed to help Grace transfer herself back into bed.
28	Grace transferred from the Smart Chair to the bed and returned to sleep.	

Table 42 The Scenario 05-A: Multiple Activity Scenario

2) Portion B: No. 29-42

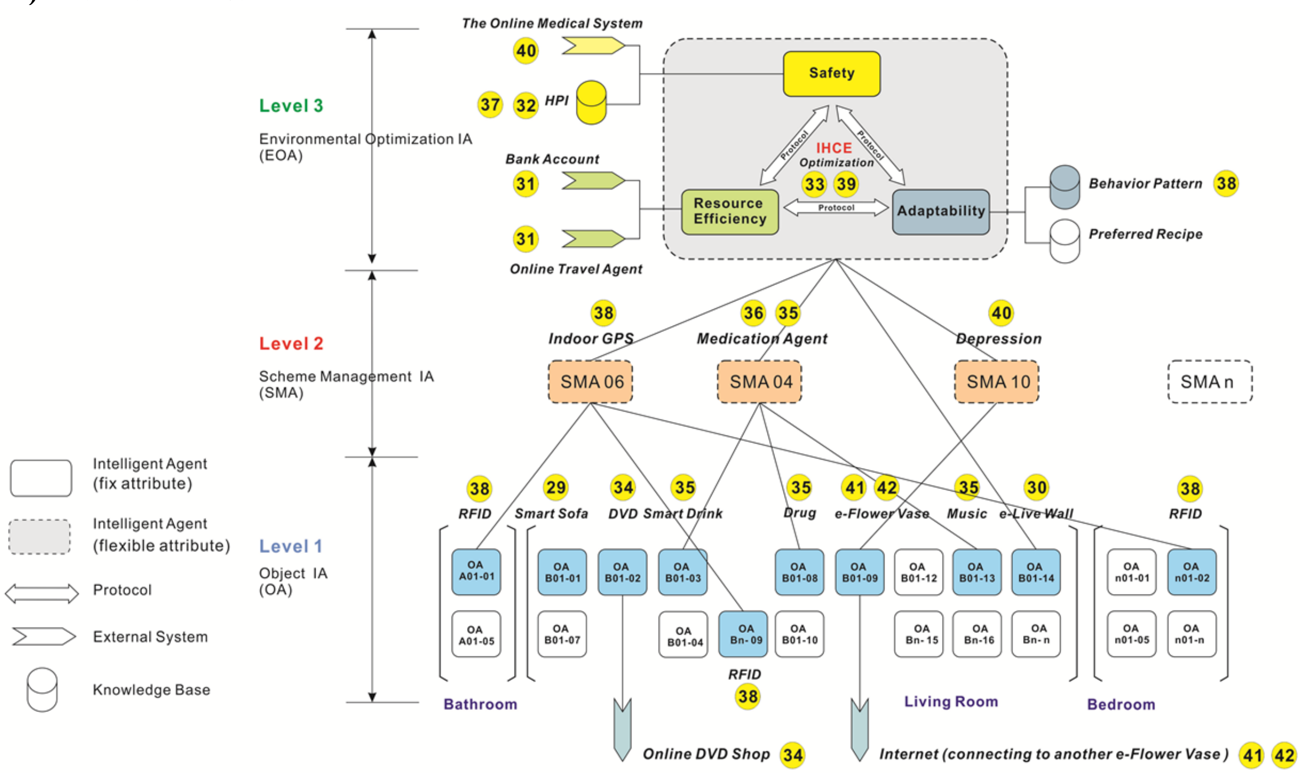


Fig. 43 The diagram of system testing for Scenario 05 (Portion B)

No.	The User's Activities (Events)	IHCE's Protocols (System responses)
29	Grace was reading a novel in the living room in the morning.	
30	The novel triggers a memory of seeing a famous show with her daughter, Alice, in Las Vegas. Grace would like to see the show again and asked IHCE for related information through e-Live Wall.	
31		Resource Efficiency Agent searches for all the required costs and figures out that an off-peak

		travel season is coming this month. It's less expensive to travel within this month.
32		Yet Safety Agent checks Grace's HPI and shows that she should avoid air travel for the next six months due to her having a heart operation three months earlier.
33		After optimization between Resource Efficiency Agent and Safety Agent, IHCE suggests that Grace consider seeing the show several months later, or alternatively, to purchase a DVD recording of the show.
34	Grace decided to purchase a DVD online but still felt depressed. She missed the experience of staying with her daughter. Yet occasionally Grace has had some conflicts with her daughter.	
35		IHCE instructs the Medication Agent (SMA 04) to remind Grace that it is time for her medication and to assist.
36	Grace did not respond to the Medication Agent's assistance and had already declined her scheduled medication twice today.	
37		Medication Agent reports Grace's medication status to IHCE.
38		IHCE checks with Indoor GPS Agent (SMA 06) and Grace's behavior pattern, knowing that Grace is still moving around in the house as usual with regular activities today, with the exception of taking her medication.
39		IHCE assumes that the reason why Grace missed medication might be due to psychological issues.
40		IHCE reports this data to the doctor and formulates Depression Agent (SMA 10) for assistance.
41		Depression Agent manages the e-Flower Vase for assistance. The e-Flower Vase allows Grace to interact with her daughter unobtrusively, detecting each other by being aware of movement in an unobtrusive, ambient way.
42	Through seeing the e-Flower Vase changing color and smelling its fragrance, Grace knew that her daughter was doing well and felt her presence while reading the novel, without the complication of any occasional conflicts when staying with her daughter in person.	

Table 43 The Scenario 05-B: Multiple Activity Scenario

3) Portion C: No. 43-55

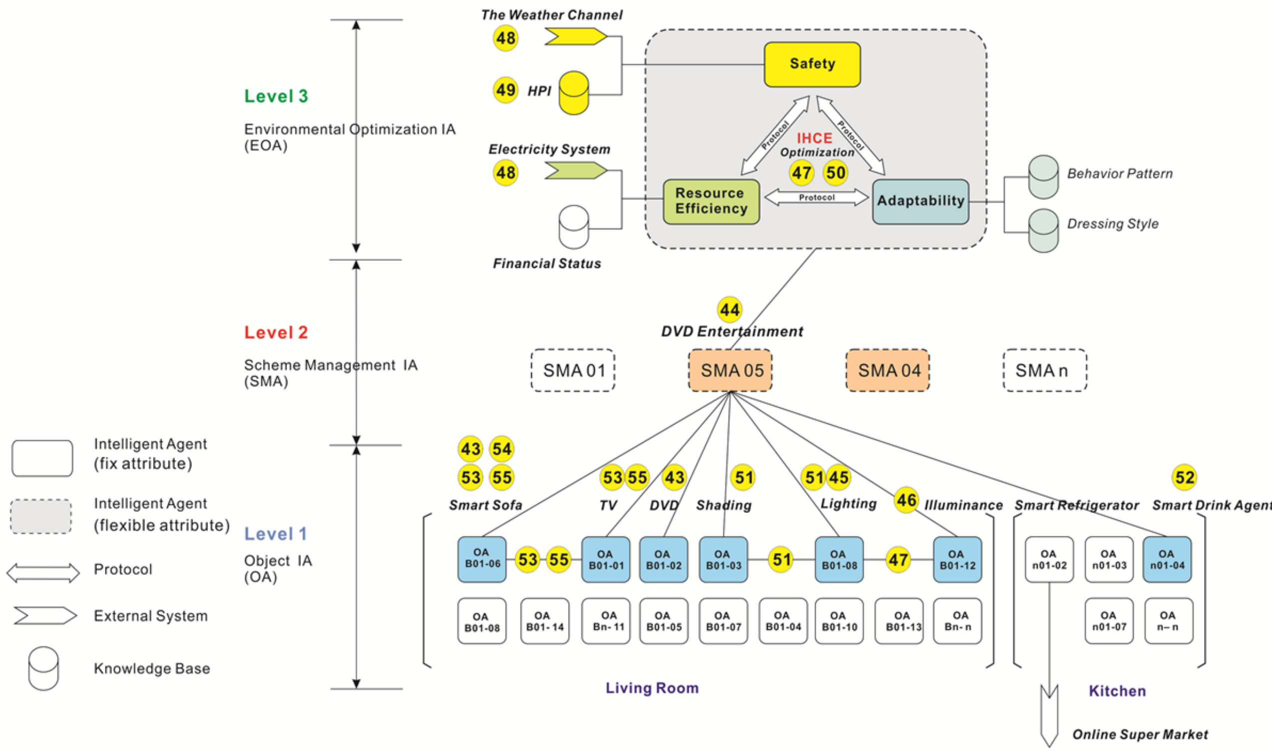


Fig. 44 The diagram of system testing for Scenario 05 (Portion C)

No.	The User's Activities (Events)	IHCE's Protocols (System responses)
43	In the afternoon, Grace sat down on the Smart Sofa in the living room and began watching a DVD.	
44		IHCE formulates DVD Entertainment Agent to help Grace. DVD Entertainment Agent is a pre-programmed Scheme Management Agent that is responsible for proposing optimized assistance for Grace when watching a DVD. Once the DVD player is turned on, DVD Entertainment Agent will be launched automatically.
45		DVD Entertainment Agent manages the Lighting Agent in the living room, sensing Grace's movement, and would typically turn on the light.
46		DVD Entertainment Agent manages Illuminance Agent, sensing that the brightness in the living room is strong enough, and reduces lighting to save energy.
47		A conflict exists between the Lighting Agent and the Illuminance Agent. DVD Entertainment Agent consults IHCE for

		optimization.
48		Resource Efficiency Agent proposes to turn off the light and bring more natural light into the room, saving energy in the daytime.
49		The Safety Agent checks Grace's HPI and notes that because Grace has cataracts, she is very sensitive to strong light, e.g. direct sunlight.
50		After optimization, IHCE manages DVD Entertainment Agent to execute optimized assistance: 1) Lightness control 2) Drink preparation 3) Sitting posture monitoring
51		DVD Entertainment Agent coordinates the Lighting Agent and the Shading Agent by turning on some of the lights and closing the shutters partially to avoid direct sunlight.
52		DVD Entertainment Agent coordinates Smart Drink Machine to prepare carrot juice for Grace that may help improve her vision.
53		DVD Entertainment Agent coordinates the Smart Sofa and television to monitor Grace's sitting posture for her back problems.
54	Grace was fascinated with the movie and had been sitting for more than 40 minutes without moving from the Smart Sofa.	
55		DVD Entertainment Agent gradually turns the volume of the TV down and flashes a notice on the TV screen encouraging Grace to move back and forth and suggesting that she interact with the back of the Smart Sofa to restore the volume, forcing her to stretch, and providing relief to her spine and back before she experiences discomfort.

Table 44 The Scenario 05-C: Multiple Activity Scenario

7.4 System Testing and Evaluation with Scenarios

To test the proposed IHCE system, this section utilizes diagrams of Dynamic Multi-Agent System (DMAS) to examine each scenario step by step for external validity from four perspectives: 1) the ability to assist the elderly with physical and cognitive functioning re-actively and proactively, and 2) the ability of proposing optimized assistance in home care with the paramount goals of safety, resource efficiency, and adaptability, and 3) the ability to demonstrate different characteristic of intelligent agents, and 4) the ability to support the user's personal taste based on their social and cultural perspectives. Meanwhile, five categories of design criteria mentioned in *Section 4.2.3* are applied for evaluating the system as follows (Table 45):

Number	1	2	3	4	5
Category	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
Criteria	▪ ADL ▪ IADL	▪ Sense of Control ▪ Sense of Coherence ▪ Self-Efficacy	▪ Safety ▪ Resource Efficiency ▪ Adaptability	▪ Reactive ▪ Proactive ▪ Social ▪ Autonomous ▪ Flexible	▪ Pragmatic ▪ Symbolic ▪ Aesthetic

Table 45 System Evaluation Criteria

The details of system testing and evaluation for each scenario are concluded in the corresponding tables (Table 46-52) from the five perspectives of design criteria in *Section 7.4.1-7.4.5*.

7.4.1 Scenario 01: Dressing/ Bathing/ Laundry

Category / No.	The User's Activities (Events)	IHCE's Protocols (System responses)	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
1	Alice woke up at 6:30 am in the winter and got out of bed.						
2		Exercise Agent (SMA 01) is activated when it sensed Alice getting out of bed. The Exercise Agent is a preprogrammed Scheme Management Agent (SMA) that is responsible for proposing optimized assistance for exercise. Once the subject wakes up after 6:00 a.m. and gets out of the bed, the Exercise Agent is automatically activated.	▪ADL	▪Sense of Coherence	▪ Safety ▪ Resource Efficiency ▪ Adaptability	▪Proactive ▪Autonomous	▪Pragmatic ▪Symbolic ▪Aesthetic
3		After consulting Safety Agent and Adaptability Agent regarding current weather conditions and exercises currently recommended by	▪ADL	▪Sense of Control ▪Sense of Coherence	▪Safety ▪Adaptability	▪Reactive ▪Social	▪Pragmatic

		her physician or physical therapist, the Exercise Agent suggests that Alice consider taking a walk.					
4	Alice decided to walk in the neighborhood for exercise and requested IHCE to suggest appropriate clothes through the Smart Closet.		▪ADL	▪Self-Efficacy			
5		Exercise Agent consults Safety Agent, Resource Efficiency Agent, and Adaptability Agent for an optimized solution regarding appropriate clothes that are suitable for Alice's health, the planned activity, personal taste and current weather conditions.	▪ADL	▪Sense of Control ▪Sense of Coherence ▪Self-Efficacy	▪ Safety ▪ Resource Efficiency ▪ Adaptability	▪Reactive ▪Social ▪Flexible	▪Pragmatic ▪Symbolic ▪Aesthetic
6		Exercise Agent manages the Smart Closet to show the suggested outfit.	▪ ADL	▪Sense of Control		▪Reactive ▪Social	▪Pragmatic ▪Symbolic ▪Aesthetic
7	Alice retrieved the suggested clothes from the Smart Closet.		▪ ADL	▪Sense of Control ▪Sense of Coherence			▪Pragmatic ▪Symbolic ▪Aesthetic
8	Alice left her house though the main entrance for her walk.		▪ ADL	▪Self-Efficacy			
9		Exercise Agent consults Adaptability Agent regarding Alice's behavior pattern and shows that she enjoys a hot rosewater bath after a walk on a brisk winter morning.	▪ ADL	▪Sense of Coherence	▪ Adaptability	▪Proactive ▪Social ▪Autonomous	▪Pragmatic ▪Symbolic ▪Aesthetic
10		IHCE activates Bathing Agent (SMA 02) for the preparation of a hot bath.	▪ADL	▪Sense of Coherence		▪Proactive ▪Social ▪Autonomous	▪Pragmatic

11		Bathing Agent consults the Safety Agent and is instructed as to the appropriate water temperature and bathing period based on Alice's HPI.	▪ADL	▪Sense of Control	▪ Safety	▪Proactive ▪Social ▪Autonomous	▪Pragmatic
12	After walking, Alice returned to her house.		▪ADL	▪Self-Efficacy			
13		Bathing Agent coordinates the Smart Tub Agent for preparing water at an appropriate temperature with rose scent and monitors the length of Alice's bath.	▪ADL	▪Sense of Coherence	▪ Safety ▪ Adaptability	▪Proactive ▪Social ▪Autonomous	▪Pragmatic ▪Symbolic ▪Aesthetic
14	Alice walked into the bathroom and placed her dirty clothes in the e-Laundry Closet.		▪IADL			▪Reactive ▪Autonomous	▪Pragmatic
15		The e-Laundry Closet senses the dirty clothes and delivers them to the Smart Laundry Center by an automated trolley system.	▪IADL	▪Sense of Control		▪Reactive ▪Social ▪Autonomous	▪Pragmatic
16	Alice started taking a hot tub in the bathroom.		▪ADL	▪Sense of Coherence ▪Self-Efficacy			▪Pragmatic ▪Symbolic ▪Aesthetic
17		After 10 minutes, the Window Agent in the bathroom senses an elevated level of moisture and opens the window in the bathroom for ventilation. Meanwhile, the Ventilation Agent also senses high humidity and would like to turn on mechanical ventilation. The conflict between two object agents triggers intervention by the Bathing Agent, which is	▪ADL			▪Reactive ▪Social ▪Autonomous	▪Pragmatic

		at a higher level in the hierarchy.					
18		After consulting Resource Efficiency Agent and Safety Agent, Bathing Agent learns that opening the window in the bathroom in the winter might lead to a cold draft, harmful to people with coronary heart disease. Thus, the Bathing Agent directs the Ventilation Agent to turn on mechanical ventilation, leaving the window opened only slightly for fresh air.	▪ADL		▪ Safety ▪ Resource Efficiency	▪Social ▪Flexible	▪Pragmatic
19		Since Alice has coronary heart disease and hypertension, after 15 minutes of bathing the, Safety Agent manages Bathing Agent to play music (the Music Agent), reminding Alice to finish her bath within 5 minutes.	▪ADL	▪Sense of Control	▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic ▪Symbolic ▪Aesthetic
20	Alice finished her bath and leaves the bathroom.		▪ADL	• Sense of Control • Self-Efficacy			

Table 46 System testing & evaluation of Scenario 01: dressing/ bathing/ laundry

7.4.2 Scenario 02: Meal Preparation

Category / No.	The User's Activities (Events)	IHCE's Protocols (System responses)	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
1	Alice was preparing dinner in the evening and asked IHCE for assistance on the e-Live Wall.		▪IADL	▪Sense of Coherence			
2		IHCE formulates Meal Agent in response to Alice's request.	▪IADL	▪Sense of Coherence		▪Reactive ▪Social ▪Autonomous	
3		Meal Agent consults IHCE for an optimized solution.	▪IADL	▪Sense of Control ▪Sense of Coherence	▪Safety ▪Resource Efficiency ▪Adaptability	▪Reactive ▪Social	▪Pragmatic ▪Symbolic ▪Aesthetic
4		Adaptability Agent checks Alice's preferred recipe.	▪IADL	▪Self-Efficacy	▪Adaptability		▪Symbolic ▪Aesthetic
5		Safety Agent checks Alice's HPI.	▪IADL	▪Sense of Control ▪Sense of Coherence ▪Self-Efficacy	▪Safety	▪Reactive ▪Social	▪Pragmatic
6		Resource Efficiency Agent checks database reported by the Smart Refrigerator regarding the status of materials in the refrigerator, knowing that some materials are going to expire soon and should be consumed within the next few days.	▪IADL	▪Sense of Control	▪Resource Efficiency	▪Reactive ▪Social	▪Pragmatic
7		IHCE suggests Alice an optimized recipe that both fits her preference and is appropriate for her health and uses food items already on hand.	▪IADL	▪Sense of Control ▪Sense of Coherence	▪Safety ▪Resource Efficiency ▪Adaptability	▪Reactive ▪Social ▪Flexible	▪Pragmatic ▪Symbolic ▪Aesthetic
8	Alice accepted the suggested recipe.		▪IADL	▪Self-Efficacy			
9		IHCE manages Meal Agent to assist Alice step by step.	▪IADL	▪Self-Efficacy		▪Proactive ▪Social	▪Pragmatic ▪Symbolic ▪Aesthetic

10		Meal Agent manages Smart Refrigerator to show the recipe on e-Live Wall and reads it verbally step by step.	▪IADL			▪Proactive ▪Social	▪Pragmatic
11	Each ingredient that Alice uses has a QR code on its external packaging that includes cooking methods. Once Alice takes the ingredients out of the external package, all she has to do is to place them into the right kitchen appliance, e.g. the Smart Oven, based on the instruction, and place the QR code close enough to the equipment for it to be read.		▪IADL	▪Sense of Control		▪Reactive ▪Social	▪Pragmatic
12		The smart appliance reads the QR code and will control the process, e.g. the strength of the heat, cooking duration, etc.	▪IADL	▪Self-Efficacy		▪Proactive ▪Social ▪Autonomous	▪Pragmatic
13	Alice would like to take required seasoning and plates from the cabinet, yet she has back problems and has difficulty stooping down far enough or kneeling to get the objects from the lower partition of the cabinet.		▪IADL				▪Pragmatic
14		Meal Agent manages the Smart Cabinet, directing it to move the inner partitions up and down so that the required objects are available to Alice without having to bend or kneel down.	▪IADL	▪Self-Efficacy		▪Reactive ▪Social ▪Autonomous	▪Pragmatic

15	Besides, Alice has recently been suffering from mild depression and requests certain "comfort foods" from an online super market such as a slice of cake and fried chicken--food that contains excessive sugar and calories.		▪IADL	▪Sense of Control		▪Reactive ▪Autonomous	▪Pragmatic
16		Smart Refrigerator checks Alice's HPI and suggests a low calorie sugarless cake.	▪IADL		▪Safety	▪Reactive ▪Social ▪Autonomous ▪Flexible	▪Pragmatic ▪Symbolic
17		After checking Alice's meal pattern and HPI, Smart Refrigerator offers a warning message, reminding Alice that she has had fried chicken twice this week and that she should avoid a third portion this week.	▪IADL		▪Safety ▪Adaptability	▪Reactive ▪Social ▪Autonomous ▪Flexible	▪Pragmatic
18	Alice accepted the suggested sugarless cake as an adequate substitution and cancels the order of fried chicken.		▪IADL	▪Sense of Control	▪Safety ▪Adaptability	▪Social ▪Flexible	▪Pragmatic ▪Symbolic
19		Smart Refrigerator integrates Alice's meal list to her meal pattern for her doctors' future review.	▪IADL		▪Adaptability	▪Social ▪Autonomous ▪Flexible	▪Pragmatic
20		IHCE coordinates Exercise Agent to reconfigure Alice's exercise schedule for additional physical exercise (Yoga) to compensate for the consumption of extra calories.	▪IADL	▪Sense of Control ▪Self-Efficacy	▪Safety ▪Adaptability	▪Social ▪Flexible	▪Pragmatic

Table 47 System testing & evaluation of Scenario 02: meal preparation

7.4.3 Scenario 03: Fall Monitoring

Category / No.	The User's Activities (Events)	IHCE's Protocols (System responses)	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
1	Kevin finished breakfast in the kitchen at 8:00 a.m.						
2		After 30 minutes, IHCE coordinates Medication Agent (SMA 04) to remind Kevin for medication. Medication Agent is a preprogrammed scheme management agent that can assist the subject in taking medicine on schedule with accurate dose.	▪IADL	▪Sense of Coherence	▪Safety ▪Adaptability	▪Proactive ▪Social ▪Autonomous	▪Pragmatic
3		Medication Agent coordinates Music Agent to play music to remind Kevin for medication.	▪IADL	▪Sense of Coherence		▪Social ▪Autonomous	▪Pragmatic ▪Symbolic ▪Aesthetic
4		Medication Agent coordinates with the Drug Agent to prepare an accurate dose of medication.	▪IADL	▪Sense of Coherence		▪Social ▪Autonomous	▪Pragmatic
5		Medication Agent coordinates Smart Drink Agent for preparing warm water.	▪IADL	▪Sense of Coherence		▪Social ▪Autonomous	▪Pragmatic
6	Kevin heard the Music Agent's alert tone, and got up from the sofa to take his medicine.		▪IADL	▪Sense of Coherence			
7	Suddenly, Kevin lost his balance and falls down on the floor.		▪ADL				
8		Floor Agent senses an instant force corresponding with the indicator number associated with Kevin's weight.	▪ADL			▪Reactive ▪Social	▪Pragmatic

9		Floor Agent transmits this data to Emergency Monitoring Agent (SMA 05).	▪ADL			▪Proactive ▪Social ▪Autonomous	▪Pragmatic
10		Emergency Monitoring Agent cooperates with Indoor GPS Agent (SMA 06) to locate Kevin's location and movement.	▪ADL			▪Proactive ▪Reactive ▪Social ▪Autonomous	▪Pragmatic
11		Indoor GPS Agent establishes that 30 seconds have elapsed between when the Floor Agent sensed the instant force, and yet, no additional movement is detected. The Indoor GPS Agent determines that Kevin has been in the same spot for more than 30 seconds.	▪IADL			▪Reactive ▪Social ▪Autonomous	• Symbolic
12		Emergency Monitor Agent assumes that a fall might have occurred.	▪IADL	▪Self-Efficacy		▪Proactive ▪Reactive ▪Autonomous	▪Pragmatic
13		Emergency Monitor Agent coordinates several object agents for emergency: 1) Coordinate Phone Agent for calling 911 and Kevin's family/ friends. 2) Coordinate Music Agent for playing alarm to call for help from any available neighbors.	▪IADL	▪Self-Efficacy		▪Proactive ▪Reactive ▪Social ▪Autonomous	▪Pragmatic

Table 48 System testing & evaluation of Scenario 03: fall monitoring

7.4.4 Scenario 04: Suspicious Events Monitoring

Category / No.	The User's Activities (Events)	IHCE's Protocols (System responses)	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
1	After cooking lunch, Nancy forgot to entirely turn off the gas in the kitchen. Feeling sleepy, she decided to take a nap in the bedroom at 1:30 pm.						
2		At 4:30pm, the Temperature Agent in the kitchen detects that the temperature is higher than the standard value.			▪ Safety	▪ Reactive	▪ Pragmatic
3		The Mechanical Ventilation Agent in the kitchen would normally activate various electric devices to reduce the indoor temperature.	▪IADL		▪ Safety	▪ Reactive ▪ Autonomous	▪ Pragmatic
4		However, the Air Quality Agent detects that CO in the kitchen is simultaneously excessive.	▪IADL		▪ Safety	▪ Reactive	▪ Pragmatic
5		Air Quality Agent would normally turn off all electric devices in the kitchen.	▪IADL		▪ Safety	▪ Reactive ▪ Social ▪ Autonomous	▪ Pragmatic
6		A Conflict between The Mechanical Ventilation Agent and the Air Quality Agent occurs, activating the IHCE for mediation and intervention.	▪IADL			▪ Social ▪ Autonomous ▪ Flexible	▪ Pragmatic
7		IHCE formulates Suspicious Event Agent (SMA 07) to investigate the incident.	▪IADL			▪ Reactive ▪ Social ▪ Autonomous ▪ Flexible	▪ Pragmatic
8		Suspicious Event Agent coordinates different Temperature Agents in the	▪IADL		▪ Safety	▪ Reactive ▪ Social ▪ Autonomous	▪ Pragmatic

		kitchen, the living room, and the bedroom for comparison.					
9		Suspicious Event Agent detects unusual temperature differences: the temperature in the kitchen is 10 degrees higher than in the bedroom and living room, and 15 degrees higher than the current outdoor temperature.	▪IADL		▪ Safety	▪Reactive ▪Social	▪Pragmatic
10		Meanwhile, the Temperature Agent in the kitchen senses that the temperature keeps increasing at a rate exceeding 5℃ every 15 minutes.	▪IADL		▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
11		Suspicious Event Agent transmits all of the data back to IHCE for making system assumptions: 1) Some appliances in the kitchen might be faulty 2) There might be a gas leak 3) The occupant might be in danger	▪IADL		▪ Safety ▪ Adaptability	▪Reactive ▪Social	▪Pragmatic
12		IHCE formulates Emergency Agent (SMA 08) in reflect to the suspicious event.	▪IADL	▪Sense of Control		▪Reactive ▪Social ▪Autonomous	▪Pragmatic
13		Emergency Agent cuts off electricity in the kitchen.	▪IADL	▪Sense of Control	▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
14		Instead of turning on any mechanical ventilation appliances that could trigger an explosion due to a possible gas leak, the Emergency Agent coordinates Window Agents	▪IADL	▪Sense of Control	▪ Safety	▪Reactive ▪Social ▪Flexible	▪Pragmatic

			to open all the windows in the house.					
15		The Emergency Agent cooperates with the Indoor GPS Agent to check the user's location as well as movement status.	▪IADL		▪ Safety	▪Reactive ▪Proactive ▪Social ▪Autonomous	▪Pragmatic
16		The Indoor GPS Agent finds that the user has remained in the bedroom without moving for more than 30 seconds.	▪IADL		▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
17		Emergency Agent manages Music Agent to ring alarms and Lighting Agent to flash light to alert and awaken Nancy.	▪IADL		▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
18	Nancy failed to respond to the alarm or exhibited any movement.						
19		Emergency Agent consults Adaptability Agent to check the user's current behavior pattern. Adaptability Agent indicates that Nancy usually moves around in the living room or kitchen after 3:00 pm.	▪ADL		▪ Adaptability	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
20		IHCE System Assumptions: The occupant may have fainted or lost consciousness.	▪ADL	▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
21		IHCE manages Emergency Agent to call for help: 1) Coordinate Phone Agent to call 911, the building manager, the user's neighbors, and family members/ friends. 2) Continue to try to awaken Nancy by	▪IADL	▪Sense of Control ▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Reactive ▪Social ▪Autonomous	▪Pragmatic

		ringing alarms and flashing lights unceasingly.					

Table 49 System testing & evaluation of Scenario 04: suspicious events monitoring

7.4.5 Scenario 05: Multiple Activity Scenario

1) Portion A: No. 1-28

Category / No.	The User's Activities (Events)	IHCE's Protocols (System responses)	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
1	Grace woke up and got out of the bed at 2:00 a.m.						
2		Lighting in the bedroom senses Grace's movement and is turned on.	▪ADL	▪Sense of Control	▪ Safety	▪Reactive ▪Autonomous	▪Pragmatic
3		Indoor GPS System (SMA 06) is informed about Grace's movement and sends this information to IHCE.	▪ADL		▪ Adaptability	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
4		IHCE formulates Midnight Assistance Agent (SMA 09) to assist Grace. Midnight Assistance Agent is a pre-programmed Scheme Management Agent that is responsible for proposing optimized assistance for Grace in the middle of the night. Once Grace wakes up and starts to move around the house, the Midnight Assistance Agent is automatically launched.	▪ADL	▪Sense of Control ▪Self-Efficacy		▪Proactive ▪Social ▪Autonomous	▪Pragmatic
5		The Midnight Assistance Agent consults the Safety Agent and the Adaptability Agent to provide optimized assistance to Grace in the middle of the night.	▪ADL ▪IADL	▪Sense of Control ▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Reactive ▪Social ▪Autonomous	▪Pragmatic

6		The Adaptability Agent references Grace's behavior patterns and knows that 85% of the times that Grace wakes up during the night, it is to use the bathroom.		▪ Sense of Coherence	▪ Adaptability	▪ Proactive	▪ Pragmatic
7		The Safety Agent checks Grace's HPI and knows that Grace has low vision functionality, especially during late night hours.			▪ Safety	▪ Autonomous ▪ Social	▪ Pragmatic
8		IHCE instructs the Midnight Assistance Agent to provide optimized assistance especially tailored for Grace at night: visual lighting assistance.	▪ ADL	▪ Sense of Control ▪ Sense of Coherence ▪ Self-Efficacy	▪ Safety ▪ Adaptability	▪ Reactive ▪ Social	▪ Pragmatic
9	Grace walked from the bed to the bedroom door.		▪ ADL				
10		Since Grace has vision issues, the Midnight Assistance Agent manages all lighting agents in the bathroom and on the way from the bedroom to the bathroom and turns on all the lights at once.	▪ ADL	▪ Sense of Control ▪ Self-Efficacy	▪ Safety	▪ Reactive ▪ Proactive ▪ Social ▪ Autonomous	▪ Pragmatic
11	Grace walked to the bathroom.		▪ ADL	▪ Self-Efficacy			
12	Grace finished using the bathroom.		▪ ADL	▪ Self-Efficacy			
13	When returning to the bedroom, Grace dropped her sleeping cap on the floor in the living room.						
14	Grace knelt down to pick up the cap, but was unable to get up from kneeling.		▪ ADL	▪ Self-Efficacy			
15	Grace asked IHCE for assistance by saying the key phase, "help stand up."		▪ ADL	▪ Self-Efficacy		▪ Reactive ▪ Autonomous	▪ Pragmatic

16		IHCE manages the Midnight Assistance Agent for assistance.	▪ADL	▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Proactive ▪Social ▪Autonomous	▪Pragmatic
17		Midnight Assistance Agent coordinates Indoor GPS Agent to locate Grace's position.	▪ADL			▪Reactive ▪Social ▪Autonomous	▪Pragmatic
18		The Midnight Assistance Agent coordinates Smart Chair to move within Grace's reach.	▪ADL	▪Self-Efficacy		▪Social ▪Autonomous	▪Pragmatic
19	Grace held on to the back of the Smart Chair, and asked the Smart Chair to rise.		▪ADL	▪Self-Efficacy		▪Reactive ▪Autonomous	▪Pragmatic
20		The back of the Smart Chair gradually rises, helping Grace stand up.	▪ADL	▪Self-Efficacy		▪Autonomous	▪Pragmatic
21	With the assistance of IHCE, Grace returned to an upright position.		▪ADL	▪Self-Efficacy		▪Social ▪Autonomous	▪Pragmatic
22		Midnight Assistance Agent recommends that Grace sit down on the Smart Chair for a brief rest.	▪ADL	▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Proactive ▪Social ▪Autonomous	▪Pragmatic
23	Grace accepted the system recommendation and sat on the Smart Chair.		▪ADL	▪Self-Efficacy			▪Pragmatic
24		Smart Chair measures Grace's blood pressure and pulse, sending data back to Safety Agent for comparison. IHCE notices that Grace's blood pressure is higher than standard and deduces that she might feel dizzy.	▪IADL	▪Self-Efficacy	▪ Safety	▪Proactive ▪Reactive ▪Social ▪Autonomous	▪Pragmatic
25		The Smart Chair reminds Grace about her physical condition and sends a notice to her doctor through the online medical system.	▪IADL	▪Self-Efficacy	▪ Safety	▪Social ▪Autonomous	▪Pragmatic
26		The Midnight Assistance Agent coordinates with	▪ADL	▪Sense of Control ▪Self-Efficacy	▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic

		the Indoor GPS Agent and the Smart Chair, sending Grace back to the bed by moving Smart Chair with Grace sitting on it.					
27		Smart Chair adjusts its sitting height to equilibrium with the bed to help Grace transfer herself back into bed.	▪ADL	▪Self-Efficacy		▪Reactive ▪Social ▪Autonomous	▪Pragmatic
28	Grace transferred from the Smart Chair to the bed and returned to sleep.		▪ADL	▪Self-Efficacy			▪Pragmatic

Table 50 System testing & evaluation of Scenario 05: Multiple activity scenario (Portion A)

2) Portion B: No. 29-42

Category / No.	The User's Activities (Events)	IHCE's Protocols (System responses)	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
29	Grace was reading a novel in the living room in the morning.						▪Symbolic
30	The novel triggers a memory of seeing a famous show with her daughter, Alice, in Las Vegas. Grace would like to see the show again and asked IHCE for related information through e-Live Wall.		▪IADL	▪Sense of Control		▪Reactive ▪Social	▪Pragmatic ▪Symbolic
31		Resource Efficiency Agent searches for all the required costs and figures out that an off-peak travel season is coming this month. It's less expensive to travel within this month.	▪IADL	▪Sense of Control	▪ Resource Efficiency	▪Reactive ▪Social	▪Pragmatic
32		Yet Safety Agent checks Grace's HPI and shows that she should	▪IADL	▪Sense of Control	▪ Safety	▪Reactive ▪Social	▪Pragmatic

		avoid air travel for the next six months due to her having a heart operation three months earlier.					
33		After optimization between Resource Efficiency Agent and Safety Agent, IHCE suggests that Grace consider seeing the show several months later, or alternatively, to purchase a DVD recording of the show.	▪IADL	▪Sense of Control	▪ Safety ▪ Resource Efficiency	▪Reactive ▪Social ▪Flexible	▪Pragmatic ▪Symbolic
34	Grace decided to purchase a DVD online but still felt depressed. She missed the experience of staying with her daughter. Yet occasionally Grace has had some conflicts with her daughter.		▪IADL	▪Sense of Control			
35		IHCE instructs the Medication Agent (SMA 04) to remind Grace that it is time for her medication and to assist.	▪IADL	▪Sense of Coherence	▪ Safety ▪ Adaptability	▪Proactive ▪Social ▪Autonomous	▪Pragmatic
36	Grace did not respond to the Medication Agent's assistance and had already declined her scheduled medication twice today.		▪IADL				
37		Medication Agent reports Grace's medication status to IHCE.	▪IADL	▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
38		IHCE checks with Indoor GPS Agent (SMA 06) and Grace's behavior pattern, knowing that Grace is still moving around in the house as usual with regular activities today, with the exception of taking her medication.	▪ADL		▪ Adaptability	▪Reactive ▪Social ▪Autonomous	▪Pragmatic

39		IHCE assumes that the reason why Grace missed medication might be due to psychological issues.	▪IADL	▪Sense of Coherence ▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Social ▪Autonomous	• Pragmatic
40		IHCE reports this data to the doctor and formulates Depression Agent (SMA 10) for assistance.	▪IADL	▪Sense of Coherence	▪ Safety ▪ Resource Efficiency ▪ Adaptability	▪Proactive ▪Social ▪Autonomous	• Pragmatic
41		Depression Agent manages the e-Flower Vase for assistance. The e-Flower Vase allows Grace to interact with her daughter unobtrusively, detecting each other by being aware of movement in an unobtrusive, ambient way.	▪IADL	▪Sense of Control ▪Self-Efficacy		▪Reactive ▪Social ▪Autonomous	▪Pragmatic ▪Symbolic ▪Aesthetic
42	Through seeing the e-Flower Vase changing color and smelling its fragrance, Grace knew that her daughter was doing well and felt her presence while reading the novel, without the complication of any occasional conflicts when staying with her daughter in person.		▪IADL	▪Sense of Control ▪Sense of Coherence ▪Self-Efficacy		▪Reactive ▪Social	▪Pragmatic ▪Symbolic ▪Aesthetic

Table 51 System testing & evaluation of Scenario 05: Multiple activity scenario (Portion B)

3) Portion C: No. 43-55

Category / No.	The User's Activities (Events)	IHCE's Protocols (System responses)	Physical Functioning	Psychological Functioning	Optimization	Criteria of I.A.	Taste Theory
43	In the afternoon, Grace sat down on the Smart Sofa in the living room and began watching a DVD.		▪IADL				▪Pragmatic ▪Symbolic
44		IHCE formulates DVD Entertainment Agent to help Grace. DVD Entertainment Agent is a pre-programmed Scheme Management Agent that is responsible for proposing optimized assistance for Grace when watching a DVD. Once the DVD player is turned on, DVD Entertainment Agent will be launched automatically.	▪IADL	▪Sense of Control ▪Self-Efficacy		▪Proactive ▪Social ▪Autonomous	▪Pragmatic
45		DVD Entertainment Agent manages the Lighting Agent in the living room, sensing Grace's movement, and would typically turn on the light.	▪IADL		▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
46		DVD Entertainment Agent manages Illuminance Agent, sensing that the brightness in the living room is strong enough, and reduces lighting to save energy.	▪IADL		▪ Safety	▪Reactive ▪Social ▪Autonomous	▪Pragmatic
47		A conflict exists between the Lighting Agent and the Illuminance Agent. DVD Entertainment Agent consults IHCE for	▪IADL	▪Sense of Control	▪ Safety ▪ Resource Efficiency	▪Reactive ▪Social ▪Autonomous	▪Pragmatic

		optimization.					
48		Resource Efficiency Agent proposes to turn off the light and bring more natural light into the room, saving energy in the daytime.	▪IADL	• Sense of Control	▪ Resource Efficiency	▪Reactive ▪Social	▪Pragmatic ▪
49		The Safety Agent checks Grace's HPI and notes that because Grace has cataracts, she is very sensitive to strong light, e.g. direct sunlight.	▪IADL	▪Sense of Control	▪ Safety	▪Reactive ▪Social	▪Pragmatic
50		After optimization, IHCE manages DVD Entertainment Agent to execute optimized assistance: 1) Lightness control 2) Drink preparation 3) Sitting posture monitoring	▪ADL ▪IADL	▪Sense of Control ▪Self-Efficacy	▪ Safety ▪ Resource Efficiency ▪ Adaptability	▪Reactive ▪Social ▪Autonomous ▪Flexible	▪Pragmatic ▪Symbolic ▪Aesthetic
51		DVD Entertainment Agent coordinates the Lighting Agent and the Shading Agent by turning on some of the lights and closing the shutters partially to avoid direct sunlight.	▪IADL	▪Self-Efficacy	▪ Safety ▪ Resource Efficiency ▪ Adaptability	▪Social ▪Autonomous ▪Flexible	• Pragmatic
52		DVD Entertainment Agent coordinates Smart Drink Machine to prepare carrot juice for Grace that may help improve her vision.	▪IADL		▪ Safety ▪ Adaptability	▪Social ▪Autonomous	▪Pragmatic ▪Aesthetic
53		DVD Entertainment Agent coordinates the Smart Sofa and television to monitor Grace's sitting posture for her back problems.	▪IADL	▪Sense of Control ▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Reactive ▪Social	▪Pragmatic
54	Grace was fascinated with the movie and had been sitting for more than 40 minutes without moving		▪IADL				

	from the Smart Sofa.						
55		DVD Entertainment Agent gradually turns the volume of the TV down and flashes a notice on the TV screen encouraging Grace to move back and forth and suggesting that she interact with the back of the Smart Sofa to restore the volume, forcing her to stretch, and providing relief to her spine and back before she experiences discomfort.	▪IADL	▪Self-Efficacy	▪ Safety ▪ Adaptability	▪Reactive ▪Social ▪Autonomous ▪Flexible	▪Pragmatic

Table 52 System testing & evaluation of Scenario 05: Multiple activity scenario (Portion C)

7.5 Conclusion

Since constructing the proposed Intelligent Home Care Environment (IHCE) physically requires abundant financial and human resources, this research formulates a hypothetical prototype of IHCE for external validity of system testing and evaluation with different scenarios prior to building it physically. These scenarios aim to examine IHCE from four perspectives: 1) the ability to assist the elderly with physical and cognitive functioning re-actively and proactively, and 2) the ability of proposing optimized assistance in home care with the chief goals of promoting and balancing safety, resource efficiency, and adaptability, and 3) the ability to demonstrate different characteristic of intelligent agents, and 4) the ability to support the user's personal sense of taste based on their social and cultural perspectives.

The subjects in the scenarios are representative samples (personas) derived from the Healthy Aging Network Walking Studies (HANS) that included 884 people aged ≥ 65 years identified in four different locales in the United States. Each of the representative profiles have different levels of physical/ cognitive functioning and challenges, as well as different everyday tasks for which they require home care assistance. These include, Activity of Daily Living (ADL)/ Instrumental Activity of daily Living (IADL), safety issues (e.g. fall monitoring, suspicious event monitoring, and sitting posture monitoring), financial control, etc. To demonstrate how IHCEs can assist the elderly with safety, resource efficiency, and adaptability, both computational systems and smart appliances are integrated in different scenarios. Meanwhile, five categories of design criteria mentioned in *Section 4.2.3* are applied for evaluating the proposed IHCE in terms of home care services (ADL/IADL), system optimization, criteria of intelligent agents, and taste theory. Through surrogate empirical system testing and evaluation with different scenarios, the proposed model of IHCE could be improved upon based on a trial-and-error method, helping prepare for the future physical construction and application of IHCEs.

PART IV

Chapter VIII

Conclusions

The demographic trend towards an aging population is a world-wide phenomenon that is making home health care service increasingly critical. This trend is most pronounced in the developed world where birthrates have long been in decline due to urbanization, the elimination of many childhood diseases and a soaring cost of living compared to a century ago (United Nations, 1999; U.S. Census Bureau, 2000). These economic and demographic trends are shattering cultural traditions wherein children accept the responsibility of providing active care and companionship to their aged parents. With the vast majority of younger generations forming their own households, more of the elderly are living individually and independently. The relocation of the young as they search for employment opportunities, along with a rising cost of living, creates great societal challenges. Many of the elderly will require physical assistance while their children may be unable to afford adequate home care services. Medical services for the elderly, already strained, may prove insufficient in the near future.

This research starts by clarifying current issues generally in the physical environments and particularly regarding home care services. To solve these issues, this research proposes an intelligent environment as a solution to assist the elderly with physical and cognitive functioning. In thinking of designing built environments as living ecology, acupuncture theory is applied as a metaphor to formulate a Dynamic Multi-Agent System (DMAS) that can assist the elderly not only on individual Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL), but also from a holistic viewpoint: optimization of safety, resource efficiency, and adaptability. This chapter covers three perspectives to conclude this research: 1) research strength, 2) potential applications and research outcomes, and 3) future developments.

8.1 Research Strength

Intelligent Home Care Environment (IHCE) is proposed in this research as a solution for assisting the elderly. One portion of the essence of intelligent environments is the capability of prosecuting multiple tasks controlled by multi-agent systems. However, most of the current proposed intelligent environments focus only on the multiplicity of system goals, lacking of discussion about how to solve conflicts occurred among multiple Intelligent Agents (IAs). IHCE applies acupuncture theory as a metaphor to propose a new multi-agent system: Dynamic Multi-Agent System (DMAS). DMAS not only maintains the capability of prosecuting multiple system tasks, but also enables negotiations among IAs, creating flexibility within the system’s hierarchy.

IHCE can avoid unexpected conflicts between caregivers and the elderly due to social and cultural differences. Meanwhile, it also provides optimized solutions from a holistic perspective instead of merely "ad-hoc" assistance. For instance, a person who has weak lower-body functioning may not only need assistance standing up while stooping over or kneeling down, but also benefit from a wide variety of other assistance concurrently, e.g. walking in the middle of the night, fall monitoring, and the monitoring of posture while seated. All the three main system goals – safety, resource efficiency, and adaptability – will be considered by IHCE for optimization simultaneously while providing home care service. Meanwhile, the sequence of assistance is also valuable in IHCE. For instance, in Scenario 01, IHCE can help the user on Activities of Daily Living (ADLs), by anticipating that she would greatly appreciate a hot rosewater bath after walking on a winter morning, followed by listening to a sonata by Mozart's while drinking green tea in the living room. In the on-site case study, each time the subject is assisted by different caretakers, she has to inform and instruct each individual care-giver about her preferred sequence of home care service. Only limited caregivers are either capable of remembering or willing to respect the subject's preference. IHCE can assist the subject honestly without having the subject bargaining with caregivers that might cause conflict, stress and occasional depression. Meanwhile, IHCE assist the elderly not only on pragmatic requirements, but also from an aesthetic viewpoint while respecting the user's personal taste (Cranz, 2004). Besides, IHCE contains multiple subsystems and knowledge bases that act as various expert systems (Kalay, 2004), assisting the elderly based on up-to-date information resources, e.g. the user's History of the Present Illness (HPI) or the latest weather conditions. These subsystems enable IHCE to make decisions with more abundant information than that available to an individual caretaker.

From the viewpoint of Actor-Network Theory (ANT), Bruno Latour interprets human-environmental interactions through a social network comprising both humans and objects as participants (Latour, 2007). Since IHCE comprises many smart appliances and human-computer interfaces that allow the elderly to interact with and control their own environment to a degree, it enables the user to broaden their sensorium and social network independently through new technologies, providing various levels of empowerment. For instance, in Scenario 5, the user can sense her daughter's presence through Ambient Media [27] by seeing two e-Flower vases connected through the Internet while they are physically apart. In this way, both of them can still focus on their primary tasks without interrupting each other's activities, but are still kept socially engaged (Rowe & Kahn, 1997). This advantage is something that traditional home care services cannot provide.

Moreover, with the assistance of new technologies, new ways of home care service can be provided as well. For instance, in Scenario 5, through interacting with the Smart Sofa, the user can manipulate multiple electric devices, e.g. the television and DVD player, and benefit from the process of Human-Computer Interaction (HCI) while moving their upper body forward and backward for stretching out (Kaptelinin & Nardi, 2006; McCullough, 1999; Moggridge, 2007). This process of HCI can also provide postural pluralism that benefits the user from the viewpoint of body conscious design (Cranz, 2000).

[27] Ambient Media is an approach that conveys information via calm changes (Calm technology) in the environment so that users are more able to focus on their primary tasks while staying aware of non-critical but important information that affects them (Pousman & Stasko, 2006). Calm Technology engages both the center (foreground activities) and the periphery (background activities) of our attention, and moves back and forth between the two (Buxton, 1997).

8.2 Potential Applications & Research Outcomes

The main potential applications and outcomes of this research are threefold: 1) Dynamic Multi-Agent System (DMAS), 2) Special Event Sub-systems, and 3) Human-Computer Interface (HCI) Design.

Dynamic Multi-Agent System applies Acupuncture Theory as a metaphor that develops a new multi agent-based intelligent environment with the following characteristics: 1) the dynamic hierarchy, 2) multiple subsystems and control scopes. As addressed in *Section 6.4.1*, this holistic multi-agent system contains both centralized IAs and multiple distributed IAs that interacts with multiple occupants' behavior separately, and has the ability to make decisions from a holistic viewpoint through optimization. Except home care services, DMAS can be applied to any other application with different subjects that require multi-agent systems.

Besides, in response to different levels of requirements for home care services, if the proposed IHCE cannot be built out entirely, some sub-systems can be formulated and packaged separately as independent systems for applications. Each sub-system comprises DMAS and different corresponding smart appliances or HCI designs. Here is the list of these special event systems: the Smart Laundry System, the Smart Laundry Center, Fall Monitoring System, Suspicious Events Monitoring System, and Posture Monitoring System.

Meanwhile, some of the aforementioned smart appliances or HCI designs can also be developed as independent products with embedded IAs. The list of these potential products is as follows: the e-Laundry Closet, the Smart Dressing Closet, the Smart Cabinet, the Smart Refrigerator, the Smart Oven, the Smart Drink Machine, the Smart Sofa, the e-Flower Vase, and the Smart Chair.

8.3 Future Directions

The proposed Intelligent Home Care Environment (IHCE) in this research is a theoretical model that comprises Dynamic Multi-Agent Systems and multiple smart appliances. The next step in this research is to construct the entire IHCE in the physical world for system testing. With a sufficient quantity of effective subjects, the proposed IHCE can be tested and evaluated more accurately. Besides, the financial expenses between hiring a 24-hour caregiver and building an IHCE for the elderly are not compared at this stage. The expenses of constructing IHCEs depend on the maturity of technologies. According to the history of the development of personal computers, the cost of building IHCEs will decrease sharply once the technologies are well developed in the future.

The Intelligent Home Care Environment provides a solution to Aging issues. The purpose of IHCE is not to entirely replace human home care assistants with new technologies, but to relieve the burden of caregivers from some repetitive tasks, e.g. medication, laundry, etc. Some forms of home care assistance still require human caretakers, such as feeding. Furthermore, the touch and interaction with real human beings is irreplaceable, especially amongst the elderly who may find such advanced technology foreign and confounding. However, under the current system of home health care delivery, some degree of conflict between caregivers and the elderly are inevitable. In thinking of limited medical resources and all the aforementioned issues of current solutions on home care service, IHCE aims at assisting the elderly in more respects, helping them live independently, achieve greater satisfaction, and have a well-balanced, successful aging (Rowe & Kahn, 1997; Satariano, 2006).

Bibliography

American Medical Association. (2001). *The American Medical Association guide to home caregiving*. New York: J. Wiley & Sons.
Antonovsky, A. (1979). *Health, stress, and coping: New perspectives on mental and physical well-being*: Jossey-Bass Inc Pub.
Bandura, A. (1997). *Self-efficacy: The exercise of control*: Worth Publishers.
Bennett, C. (1977). *Spaces for people : human factors in design*. Englewood Cliffs, N.J.: Prentice-Hall.
Blank, A. E. O. M. S. S. A. (2007). Choices in palliative care issues in health care delivery, from http://dx.doi.org/10.1007/978-0-387-70875-1
Brager, G., & de Dear, R. (2003). Historical and cultural influences on comfort expectations. *Buildings, Culture and Environment: Informing local and global practices*, 177.
Brand, S. (1994). *How buildings learn : what happens after they're built*. New York, NY: Viking.
Buchenau, M., & Suri, J. (2000). *Experience prototyping*.
Buhler-Wilkerson, K. (2001). *No place like home : a history of nursing and home care in the United States*. Baltimore: John Hopkins University Press.
Bumagin, V. E. H. K. F. (2001). *Caregiving : a guide for those who give care and those who receive it*. New York: Springer Pub.
Burau, V. D. T. H. B. R. H. (2007). *Governing home care : a cross-national comparison*. Cheltenham, UK; Northampton, MA: Edward Elgar.
Buxton, W. (1997). Living in augmented reality: Ubiquitous media and reactive environments. *Video mediated communication*, 363-384.
C.P. Germain. (1992). Cultural care: A bridge between sickness, illness, and disease. *Holistic Nursing Practice, 6*, 1-9.
Chen, J., Ma, Y., Jeng, T., & Chang, C. (2010). An assessment of user needs for intelligent living space. *Intelligent Buildings International, 2*(1), 20-40.
Corbusier, L. (1923). Towards a new architecture. *Trans. F. Etchells. New York: Dover. First published as Vers une Architecture in*.
Cranz, G. (1990). A New look at the Person in Person-Environment Relations: Theoretical Assumptions About the Body. [Working Papers]. *The Center for Environmental Design Research*.
Cranz, G. (2000). *The chair: rethinking culture, body, and design*: WW Norton & Company.
Cranz, G. (2004). A New Way of Thinking about Taste. *The Nature of Craft and the Penland Experience*, 130-136.
Cranz, G. (2010). Lying Down on the Job, Literally. *Is All That Sitting Really Killing Us?* Retrieved from http://roomfordebate.blogs.nytimes.com/2010/04/23/is-all-that-sitting-really-killing-us/
Darren Murph. (2010). Intel Infoscape HD wall brings real-time web visualization (hands-on) from http://www.engadget.com/2010/01/10/intel-infoscape-hd-wall-brings-real-time-web-visualization-hand/

de Ruyter, B. (2003). 365 days ambient intelligence research in Homelab. *Philips Research, The Netherlands*.
Deadman, P., Al-Khafaji, M., & Baker, K. (2007). *A manual of acupuncture*. Hove, East Sussex, England; Vista, Calif., USA: Journal of Chinese Medicine Publications ; Distributed in North America by Eastland Press.
Diamond, T. (1992). *Making gray gold : narratives of nursing home care*. Chicago: University of Chicago Press.
Doi, S., Ito, A., Tohyama, T., Takeda, Y., Fukano, T., Takeichi, A., & Suzuki, H. (2005). Development of dye-sensitized solar modules to meet artistic designs 1. Wall-integrated panels for TOYOTA Dream House:"PAPI". *Proceedings of WCWRF 2005*.
Ferrucci, L., Guralnik, J., Simonsick, E., Salive, M., Corti, C., & Langlois, J. (1996). Progressive versus catastrophic disability: a longitudinal view of the disablement process. *J Gerontol, 51*, M123-M130.
Francine Rainone, & McHugh, M. (2007). Patient-Centered Palliative Care in the Home *Choices in Palliative Care* (pp. 31-44): Springer.
French Jean, & R, S. D. (1973). Terminal Care at Home in Two Cultures. *The American Journal of Nursing, 73*, 502-505.
Fuller, B. (1965). Conceptuality of fundamental structures. *Structure in Art and in Science*, 66-88.
Galanti, G.-A. (1991). *Caring for patients from different cultures : case studies from American hospitals*. Philadelphia: University of Pennsylvania Press.
Georgia Tech., E. U. (2005). The Health Systems Institute, HSI from http://www.hsi.gatech.edu/
Geri-Ann Galanti. (1999). Caring for Culturally Diverse Patients at Home. *Home Health Care Consultant, 6*, 33-34.
Hall, E. T. (1966). *The hidden dimension*. Garden City, N.Y.: Doubleday.
Harris, M. D. (1994). *Handbook of home health care administration*. Gaithersburg, Md.: Aspen.
Harris, M. D. (2005). *Handbook of home health care administration*. Sudbury, Mass.: Jones and Bartlett Publishers.
Hartkopf, V., Loftness, V., Mahdavi, A., Lee, S., & Shankavaram, J. (1997). An integrated approach to design and engineering of intelligent buildings-The Intelligent Workplace at Carnegie Mellon University. *Automation in construction, 6*(5-6), 401-414.
Helal, S., Mann, W., El-Zabadani, H., King, J., Kaddoura, Y., & Jansen, E. (2005). The gator tech smart house: A programmable pervasive space. *Computer*, 50-60.
Holmquist, L., Redström, J., & Ljungstrand, P. *Token-based access to digital information*.
Iezzoni, L. I. (2002). Toward Universal Design in Assessing Health Care Experiences. *Medical Care Medical Care, 40*(9), 725-728.
Intel_Proactive_Research. (2004). The Center for Aging Services Technologies, CAST from http://www.intel.com/pressroom/archive/releases/2004/20040316corp.htm; http://www.aahsa.org/cast.aspx
Ishii, H., & Ullmer, B. (1997). *Tangible bits: towards seamless interfaces between people, bits and atoms*.
Jaffe, M. S. S.-R. L. J. M. S. (1997). *Home health nursing : assessment and care planning*. St. Louis: Mosby.
Kalay, Y. (2004). *Architecture's new media*: MIT Press.
Kaptelinin, V., & Nardi, B. (2006). *Acting with technology: Activity theory and interaction design*: MIT Press Cambridge, MA.

Karen Hanson. (2012). Nursing Home Church Retrieved January 12th, from http://healingasasacredpath.blogspot.com/2012_01_01_archive.html
Katz, S., Ford, A., Moskowitz, R., Jackson, B., & Jaffe, M. (1963). Studies of illness in the aged: the index of ADL: a standardized measure of biological and psychosocial function. *Jama, 185*(12), 914.
Kee, E. (2010). Smart Fridge hopes to keep you healthy, from http://www.ubergizmo.com/2010/05/smart-fridge-hopes-to-keep-you-healthy/
Kohout, F. J. B. L. F. E. D. A. C.-H. J. (1993). Two Shorter Forms of the CES-D Depression Symptoms Index. *Journal of Aging and Health Journal of Aging and Health, 5*(2), 179-193.
Lang, A. E. N. F. A. (2008). Safety in home care: a broadened perspective of patient safety. *International Journal for Quality in Health Care, 20*(2), 130-135.
Larson, K. (2002). MIT House_n project, from http://architecture.mit.edu/house_n/index.html
Latour, B. (2007). *Reassembling the social*: Oxford University Press.
Lawton, M., & Brody, E. (1969). Instrumental activities of daily living scale (IADL). *The Gerontologist, 9*, 179–186.
Lawton, M., & Nahemow, L. (1973). Ecology and the aging process. *The psychology of adult development and aging*, 619-674.
Leininger, M. (1991). Leininger's acculturation health care assessment tool for cultural patterns in traditional and non-traditional lifeways. *Journal of transcultural nursing : official journal of the Transcultural Nursing Society / Transcultural Nursing Society, 2*(2), 40-42.
Lipson Jg, M. A. I. (1985). Culturally appropriate care: the case of immigrants. *Topics in clinical nursing, 7*(3), 48-56.
Lipson, J. G. M. P. A. D. S. L. (1996). *Culture & nursing care : a pocket guide*. San Francisco: UCSF Nursing Press.
M.C. Narayan. (1997). Cultural Assessment in Home Health Care. *Home Health Care Nurse, 15*, 663-670.
Maciocia, G. (2008). *The practice of Chinese medicine : the treatment of diseases with acupuncture and Chinese herbs*. Edinburgh; New York: Churchill Livingstone/Elsevier.
Margaret M. Andrews, & Boyle, J. S. (2011). *Transcultural Concepts in Nursing Care* (Sixth ed.): Lippincott Williams & Wilkins.
Marie E. Cowart, & Streib, G. F. (1987). Taiwan and Its Elderly: Taxi Nurses and Home Care. *Applied Gerontology, 6*, 156-162.
McCullough, M. (1999). *Abstracting Craft*: MIT press.
Mercer, S. O. (1996). Navajo Elderly People in a Reservation Nursing Home: Admission Predictors and Culture Care Practices. *Social work., 41*(2), 181.
Ming-Tung Chen. (2000). *Conduction of Energy and Qi*. Taichung: National Chinese Qi Healing Association.
Minker, W., Weber, M., & Hagras, H. (2009). *Advanced Intelligent Environments*: Springer Verlag.
Minsky, M. (1988). *The society of mind*: Simon & Schuster.
Mitchell, W. (2000a). *City of bits: space, place, and the infobahn*: MIT press.
Mitchell, W. (2000b). *E-topia:"Urban life, Jim--but not as we know it!"* the MIT Press.
Mitchell, W. (2004). *Me++: The cyborg self and the networked city*: The MIT Press.
Mitty, E. L. (2005). Culture Change in Nursing Homes: An Ethical Perspective. *ANNALS OF LONG TERM CARE, 13*(3), 47-51.

Moggridge, B. (2007). *Designing Interactions* (1 ed.). Cambridge: The MIT Press.
Monks, K. (2000). *Pocket guide to home health care*: WB Saunders Co.
Monks, K. (2002). *Home Health Nursing: Assessment and Care Planning* (4 ed.). New York: Mosby.
Montauk, S. (1998). Home health care. *American Family Physician, 58*, 1608-1616.
Montauk, S. L. (1998). Home health care. *American Family Physician, 58*(7), 1608-1614.
Mossaic Home Care Services. (2013). Mossaic Home Care Services, from http://homecarecostablanca.com/
Mozer, M. (1998). *The neural network house: An environment that adapts to its inhabitants*.
Mozer, M. (1999). An intelligent environment must be adaptive. *IEEE Intelligent Systems and their applications, 14*(2), 11-13.
Murashima, S. N. S. M. J. K. F. S. K. M. (2002). Home Care Nursing in Japan: A Challenge for Providing Good Care at Home. *Public Health Nurs Public Health Nursing, 19*(2), 94-103.
Negroponte, N. (1970). *The architecture machine*: MIT press Cambridge.
Negroponte, N. (1975). *Soft architecture machines*: MiT Press Cambridge.
Ni, M. (1995). *The Yellow Emperor's Classic of medicine : a new translation of the Neijing Suwen with commentary*. Boston: Shambhala.
Norvig, P. (2003). *Artificial intelligence: a modern approach*: Pearson Education.
Padgham, L., & Winikoff, M. (2004). *Developing intelligent agent systems: a practical guide*: Wiley.
Peterson, C., Maier, S. F., & Seligman, M. E. P. (1993). *Learned helplessness : a theory for the age of personal control*. New York: Oxford University Press.
Pondy, L. (1967). Organizational conflict: Concepts and models. *Administrative Science Quarterly*, 296-320.
Pousman, Z., & Stasko, J. (2006). *A taxonomy of ambient information systems: four patterns of design*.
Preiser, W., & Ostroff, E. (2001). *Universal design handbook*: McGraw-Hill Professional.
Prieto, E. (2008). Home health care provider a guide to essential skills, from http://site.ebrary.com/id/10265560
QR code.com. (2013). What is a QR Code ? , from http://www.qrcode.com/en/about/
Rapoport, A. (1990a). *History and precedent in environmental design*: Plenum Publishing Corporation.
Rapoport, A. (1990b). *The meaning of the built environment: A nonverbal communication approach*: University of Arizona Press Tucson, AZ.
Rowe, J., & Kahn, R. (1997). Successful aging. *The Gerontologist, 37*(4), 433.
Sakamura, K. (1990). The TRON Intelligent House. *IEEE MICRO, 10*(2), 6-7.
Sakamura, K. (1996). The tron project. *Information and Software Technology, 38*(3), 239-251.
SamSung. (2007). SamSung Home vita, from http://210.118.57.197/HomeNetwork/SAMSUNGHomeVita/Index.htm
Satariano, W. (2006). *Epidemiology of aging : an ecological approach*. Sudbury, Mass.: Jones and Bartlett Publishers.
Seligman, M. E. P. (1975). *Helplessness : on depression, development, and death*. San Francisco; New York: W.H. Freeman ; Trade distributor, Scribner.
Smedley, B., Syme, S., Sampson, R., & Morenoff, J. (2000). Promoting Health: Intervention Strategies from Social and Behavioral Research.

Springhouse Corporation. (2001). *Pocket guide to home care standards : complete guidelines for clinical practice, documentation, and reimbursement*. Springhouse, Pa.: Springhouse Corp.
Steinfeld, E. (1975). *Barrier-free design for the elderly and the disabled*: Syracuse University.
Steinfeld, E. (1979). *Access to the built environment: a review of literature*: The Office: for sale by the Supt. of Docs., US Govt. Print. Off.
Story, M. F., Mueller, J., & Mace, R. L. (1998). *The universal design file : designing for people of all ages and abilities*. [North Carolina]: NC State University, Center for Universal Design.
Sutton, R., & Barto, A. (1999). Reinforcement learning. *Journal of Cognitive Neuroscience, 11*(1), 126-134.
Syme, S. (1989). Control and health: a personal perspective. *Stress, personal control and health. Bruselas: John Wiley & Sons*.
Takeyama, H., & Sakamura, K. (1989). Design and implementation of the ITRON specification--an embedded industrial realtime OS. *MICROPROCESS. MICROSYST., 13*(8), 514-524.
The Architecture and Building Research Institute, A. (2009). Living 3.0: Intelligent Living Space, from http://www.living3.org.tw/ils-museum/e-intro.aspx
The Aware Home Research Institute (AHRI), G. T. (2002). The Aware Home from http://awarehome.imtc.gatech.edu/
Thrift, N. (2007). *Non-representational theory: space, politics, affect*: Routledge.
Trekky. (2011, July 23). Ribbon woven QR code (picture overload), from http://www.craftster.org/forum/index.php?topic=386599.0#axzz2c6bAwZM5
Veith, I., & Rose, K. (2002). *The Yellow Emperor's classic of internal medicine*: Univ of California Pr.
Verbrugge, L., & Jette, A. (1994). The disablement process. *Social Science &amp*, 1-14.
Virginia Hospital Center. (2013). An all-private patient room in the Hospital, from http://www.centerforbreasthealth.com/breastsurgeryjourney.shtml
Weiser, M. (1995). The computer for the 21st century. *Scientific American, 272*(3), 78-89.
Weiss, G. (2000). *Multiagent systems: a modern approach to distributed artificial intelligence*: The MIT press.
William A. Satariano, Susan L. Ivey, Elaine Kurtovich, Melissa Kealey, Alan E. Hubbard, Constance M. Bayles, . . . Thomas R. Prohaska. (2010). Lower-body function, neighborhoods, and walking in an older population. *American journal of preventive medicine, 38*(4), 419-428.
Wooldridge, M. (2002). An introduction to multiagent systems. . *West Sussex, England: John Wiley and Sons Ltd, 348*.
Woven Quality Labels. (2013). Smart Labels, from http://www.qualitywovenlabels.com/smart-woven-labels.htm
Zhang, Y., & Rose, K. (2001). *A brief history of qi*: Paradigm Publications.