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Abstract

Smart home technology (SHT) has been identified as a promising means of helping seniors to remain independent and maintain their quality of life (QoL) while containing spiralling care costs for older people. Despite official pilot schemes in many countries to promote SHT in seniors housing, there is limited understanding of the forms that such SHT interventions should take. This study builds on the analytical model of intelligent building control systems developed by the author; the aim is to provide a systematic approach to understanding the key intelligent attributes of smart-home devices. A qualitative participatory evaluation approach involving focus groups was adopted to investigate the needs of seniors and their SHT preferences. Fourteen features of the SHT technical requirements of four key intelligent attribute types were identified. This study's insights will help to shape the way SHT is designed and used.

Keywords

Smart home technology; technical requirements; intelligent attributes; seniors; ageing in place

Introduction

In recent years, Hong Kong, like many other places in the world, has encountered the challenges of a sharp increase in the proportion of older people in the overall population and an increasing number of older adults living independently. Residential living environments have a strong influence on to the physical and psychological well-being of older people (Rioux, 2005; Oswald et al., 2007). Past research shows that older people are likely to spend more time (i.e. 80% of their time) at home than other age groups (Baltes et al., 1999; Iwarsson et al., 2007). The person-environment (P-E) fit model (Lawton and Nahemow, 1973) posits that older adults become increasingly reliant on their surroundings, such as their physical living environment, to offset functional decline as they age (Brawley, 2001). To accommodate the demographic shift towards an older population, it is suggested that home environments should be designed to accommodate losses in physical function, and thus enhance the independence of older adults in their daily activities and increase their autonomy (Lawton and Nahemow, 1973; Gill et al., 1999).

The significant advances in microprocessor-based technologies over the last decade have led to the emergence of home automation and intelligent control technologies that provide convenience, comfort, energy efficiency, security and better quality home environments (Wong et al., 2005; van Hoof and Kort, 2009). Smart home technologies (SHT) have been proposed as a method for helping older people to maintain independent living and safety at home; they can perform some of the activities of daily living (ADLs), predict normal and abnormal behaviour and alert caregivers to potentially dangerous behaviour (Blaschke et al., 2009; World Health Organization, 2012). SHT include a range of emergency assistance systems, security and safety features, fall prevention features, sensors and timers that aim to monitor the daily functioning of the older adults at home and to reduce falls, disability, stress, fear and social isolation (Barlow and Venables, 2004). For example, real-time monitoring and detection of accidental falls or slips amongst older people (Yu, 2008) would ensure timely first-aid by caregivers, families or paramedics (Abbate et al, 2012). Detection of unattended cooking in kitchens, an unsafe behaviour when using a stove top, particularly by the frail older adults with intellectual disabilities, would reduce the risk of accidental and sometimes fatal fires (Yuan et al., 2012). Detection of unauthorised intrusion would maintain home security. Appropriate information and communication technology (ICT) enables social interaction monitoring and assistance for the older people; for example, health care data can be remotely transmitted to a monitoring site (i.e. hospital or clinic) from an older adult's home (TECNALIA, 2013). Arguably, a home setting equipped with SHT should reduce stress and optimise quality of life (QoL): for example, by improving functional capacity; monitoring health status; enhancing psychological wellbeing; increasing social support; improving morale; enhancing independence; and allowing for coping and adjustment. SHT also can help relieve the burden on caregivers and social support services (Demiris et al., 2008 and Blaschke et al., 2009). However, it is also possible that SHT would create feelings of confusion and anxiety in the older adults (Gardner-Bonneau and Gosbee, 1997).

A number of overseas studies have indicated that there are extensive acceptance barriers, such as privacy/ethical issues, security and accessibility, to SHT – presenting serious obstacles to the ability of SHT to provide technical solutions (Courtney, 2008; Demiris et al., 2008; Wirtz et al., 2009; Gaul and Ziefle, 2009; Tomita et al., 2010; Portet et al., 2011). To date, the influence of SHT on seniors is ill-defined and has received insufficient attention from researchers, as is the question of how future cohorts of people may benefit from SHT (Lawton, 1998, Wahl and Oswald, 2000). Hong Kong has one of the best ICT infrastructures in the world, and the percentage of households with a computer or other IT equipment connected to the Internet is almost 80% (Census and Statistics Department, 2016). Statistics also show that over 80% of people aged 55-64, and 36% of people aged 65 and over had smartphones in 2015 (Census and Statistics Department, 2016). Similarly, over 70% of citizens aged 55-64, and 30% of citizens aged 65 and over have rich computer experience (Census and Statistics Department, 2016). This implies that IT components are common in the daily activities of the older people in Hong Kong, in particular the 'younger' older people. Hong Kong is also very congested and the urban area has the highest population density in the world, which makes the city an interesting setting to investigate the potential of SHT.

The development of SHT in Hong Kong, as well as in many other cities or countries, is limited by the lack of reliable information about the human component; the specific needs and requirements of older people need to be incorporated into technical design so that appropriate technological solutions can be developed to address these needs. SHT research in Hong Kong has no knowledge of the local older adults' use or non-use of SHT (including the level), user needs and fears, or how SHT can enhance aspects of ageing in place (AIP). Most homes in Hong Kong are smaller than homes in Western countries, so the concept and application of SHT could be different in Hong Kong than in other countries. Previous study maintains that the size of the house controls the number of devices and the functionality, which in turn will affect the cost of the system (Dewsbury et al., 2001). Possibly, the potential for SHT adoption amongst the older people is larger in Hong Kong since the home is smaller - less system (e.g. sensors) required and a lower cost. Understanding the issues that are faced by seniors interacting with SHT is a necessary step in developing appropriate smart technologies and design solutions that address seniors' physical conditions. Without a clear and accurate understanding of the needs of older adults, the use and implementation of appropriate SHT to support seniors in Hong Kong is not feasible. This knowledge gap severely limits the ability of the local building sector and policy makers to make informed decisions about the adoption of SHT devices as early care solutions in future senior residential blocks/housing designs.

In addition, SHT adoption also raises questions about the nature and attributes of appropriate smart home devices (Melenhorst et al., 2006). Although enhancing the QoL of the older adults at home is considered to be a primary goal of SHT adoption, we have only a limited understanding of what smart home devices must be able to do to meet the specific requirements of older adults. Existing research lacks a systematic approach to determining which 'intelligence' performance elements should be incorporated, and how these elements can accommodate the needs of seniors' AIP requirements. These knowledge gaps and practical deficiencies have forced the industry to continuously rely on existing designs or personal caring experiences, 'gut-feeling', rudimentary judgments or a combination of these, to justify the appropriateness of smart home devices for the older people. As a result, many new but not entirely beneficial home-based technologies tools have been installed. Thus, an inadequate understanding of the needs and expectations of seniors has led to poor knowledge of which devices should be designed and provided to the market. This study builds on the existing analytical model of intelligent building control systems by the author (Wong et al. 2008a & b). The analytical model of system intelligence posited that any intelligent device holding identified intelligent attributes, including autonomy, controllability for complicated dynamics, human–machine interaction, and bio-inspired behaviour, which can help improved operational effectiveness and energy efficiency, enhanced cost effectiveness, increased user comfort and productivity, and improved safety and reliability, in buildings (Wong et al., 2008b). This model helps explore the functionalities and attributes of SHT devices that promote the AIP of seniors living independently in HK. The research objective is to identify the key intelligent attributes of smart-home devices that would benefit senior citizens in their daily lives

Development of relationships between SHT and intelligent attributes

How smart are smart home technologies? How do we determine a system's degree of smartness? These questions demonstrate the difficulties in standardising 'smartness'. This problem extends to the technical definition of SHT. Although SHT always involves the concept of home automation, it should be much more then home automation and should make use of modern information technologies. The idea of a smart home is to make living in a home more enjoyable and convenient through the application of intelligent design (Goodwin, 2013). Functionally, a smart home consists of a group of intelligent attributes that control the features of home appliances within a domestic residence (Holroyd et al., 2010). However, the technical developments needed to evaluate intelligent building systems is mainly theoretical, although there are studies evaluating environmental intelligent building performance and physical parameters (Wong, 2007; Wong, Li, & Lai, 2008), for example, a recent study conducted by Arditi, Mangano and Marco (2015).

Studies of machine intelligence in the engineering literature can provide insights into the evaluation of intelligent buildings and their subsets – SHT. Studies of machine intelligence aim to make systems and machines more intelligent by evaluating existing systems and then improving them with new designs. In a review, Bien et al. (2002) identified four key attributes of intelligent systems: autonomy, controllability of complicated dynamics, man-machine interaction and bio-inspired behaviour (Bien et al., 2002).The framework developed from these categories can be used to measure a machine intelligence quotient and the system intelligence of building control systems (e.g. Wong et al., 2008a&b; Wong and Li, 2009); this framework is adopted in this study. Two notions of common intelligent attributes, i.e. autonomy and controllability of complicated dynamics, and two notions of specific intelligent attributes, i.e. man-machine interaction and bio-inspired behaviour of intelligent control devices in building, are examined in our research (Wong et al., 2008a) (Figure 1).

Details of the four attributes of system intelligence (i.e., autonomy, controllability of complicated dynamics, man-machine interaction and bio-inspired behaviour) are discussed in Wong et al. (2008). In brief, 'autonomy' relates to the ability to perform self-operative functions, which is a characteristic of a system that minimises human intervention during the execution of tasks. This includes the ability to perform self-calibration, self-diagnostics, fault tolerance and self-tuning. In complicated dynamic systems, controllability refers to the features of a system that allow it to perform in a manner that is based on non-conventional models, adaptation, non-linearity and motion planning under uncertainty. Man-machine interaction refers to the ability of the system to embrace human-like understanding or communication, the emergence of artificial emotion and ergonomic design. A system with bio-inspired behavioural-based technology has the ability to interact with the built environment and to provide services based on biologically motivated behaviour, cognitive-based behaviour and neuro-scientific data. Table 1 summaries the scope of these four key attributes of intelligence systems by extending the ideas of Bien et al. (2002) and Wong et al. (2008a and 2008b).

Figure 1: Proposed taxonomy of key intelligent attributes of smart-home technologies (SHT) for older adults

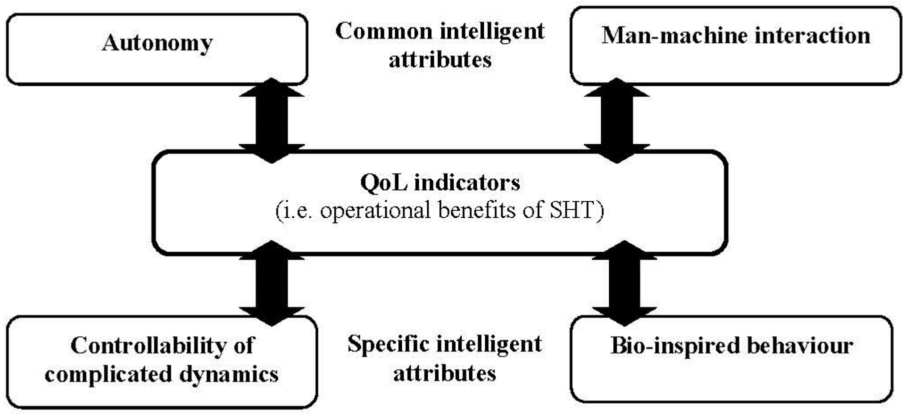

Table 1: Scope of intelligent attributes

Attribute	Scope
Autonomy	· Autonomous and independent (Liu, Jin, & Tsui, 2005) · As little human intervention as possible during the execution of tasks (Bien et al., 2002; Wong et al., 2008) · Self-operative functions (Bien et al., 2002) - self-calibration (Bien et al., 2002) - self-tuning (Bien et al., 2002) - self-diagnosis (Bien et al., 2002) - fault tolerance (Bien et al., 2002) - self-governing or having the right of self-government (Liu et al., 2005) - self-determining (Liu et al., 2005) - self-directing (Liu et al., 2005) · Ability to make independent decisions based upon observations, to plan, to draw conclusions and to make judgments concerning consequences (van Der Vyver et al., 2004) · Warranty of autonomy through guidelines and policies (van Der Vyver et al., 2004) · Independent completion of tasks by combining the planning and controlling steps (van Der Vyver et al., 2004) · Ability to learn and eliminate mistakes (van Der Vyver et al., 2004) · Ability to cooperate, in particular with other machines (van Der Vyver et al., 2004)
Controllability of complicated dynamics	· Ability to perform interactive operative functions (Bien et al., 2002) · Ability to make a very complicated dynamic system well-controlled (Bien et al., 2002) · Ability to force the system into a particular state using an appropriate control signal (Wong, 2007) · Necessity of applying learning as it arises in situations (Farrell, Berger, & Appleby, 1993) · Non-conventional model based (Bien et al., 2002) · Adaption (Bien et al., 2002) · Motion planning (Bien et al., 2002) · Non-linearity (Bien et al., 2002) · Ability to operate in conditions of uncertainty (Farrell et al., 1993)

Man-machine interaction	· Make users feel more comfortable and more human-friendly (Bien et al., 2002) · Convenient human-machine interaction (Bien et al., 2002) · Facilitate satisfactory monitoring of machines by humans (Bien et al., 2002) · Support human intervention in machine operations (Bien et al., 2002) · Help human decision-making by providing system state diagnosis intervention possibilities (Bálint, 1995) · Establish error-free or error-tolerating operation of the full system (Bálint, 1995) · Produce efficient and reliable system performance (Bálint, 1995) · Human-like understanding/communication (Bien et al., 2002) · Emergence of artificial emotion (Bien et al., 2002) - ability to display emotional expressions (Cañamero, 2005) - ability to recognise and respond appropriately to the emotional states of users (Cañamero, 2005) - be able to interact and make decisions in dynamic, unpredictable and potentially 'dangerous' environments (Wong, 2007) - simulate human behaviour in certain circumstances (Wong, 2007) · Ergonomic design (Bien et al., 2002) - achieve satisfactory performance by the operator, and by control and maintenance personnel (Beevis & Slade, 2003) - reduce skill requirements and training time (Beevis et al., 2003) - increase the reliability of personnel-equipment combinations (Beevis et al., 2003) - foster design standardisation within and among systems (Beevis et al., 2003)
Bio-inspired behaviour	· Capability of acting like a human or animal/human-like behaviour (McFarland & Bösser, 1993; Wong et al., 2008) · Ability to interact with the built environment and the services provided (Bien et al., 2002) · Biological organisms (McFarland et al., 1993; Floreano & Mondada, 1998) - biological nature of the adaptation mechanisms (Floreano et al., 1998), such as · phylogenetic evolution and ontogenetic learning · preference for behavioural stability and robustness over precision · self-organization and self-selection of goals and values · adaptation while interacting with an environment · Biological inspiration in the intelligent system (Teuscher et al., 2003) should provide - fault-tolerance - self-replication or cloning - reproduction - evolution - adaptation, learning and growth

Research Methods

This study used focus groups as the data collection method and content analysis as the technique to analyse the collected data and to determine the relevance and suitability of various intelligent indicators needed for AIP-oriented smart-home devices. We define an 'intelligence indicator' as an instrument that assesses the degree of 'intelligence' of an SHT (Wong et al. 2008a). The first step is the identification of the intelligent attributes of smart-home devices that will help seniors to age in place. Suitable intelligence indicators for various smart-home devices are identified. As older people in Hong Kong are computer literate and are the core customers in the silver market, their comments on the technical design of SHT are absolutely needed input into SHT development. Participants were recruited via fliers posted on the network of *The Institute of Active Ageing (IAA)in Hong Kong,* and also through local senior's activity centres and organisations, university websites, organisations providing care to seniors and by snowball sampling. Invitations to join the focus group discussion sessions were shared with members through the IAA's mailing list. Ninety-eight participants were recruited and were divided into 14 discussion groups (i.e. Group A to Group N). The size of each group was around 6-9 subjects. Each participant was assigned a participant code; for example, the second participant in Group C was coded as C02. All of the sessions were conducted in Cantonese (which is the most common spoken language in Hong Kong). The facilitator asked the participants about their perceptions and thoughts regarding SHT. To avoid introducing the issue of technical requirements, technical jargon was avoided by the facilitator. This approach encouraged relaxed communication for better sharing. Videos of some SHT devices were used at the beginning of each discussion to provide the participants with information about the background and concepts of SHT. Collective comments were summarized for each focus group discussion session (Kitzinger, 1994; Liamputtong, 2011). The groups' collective comments provide balance between different viewpoints.

The collected conversations of the 14 groups were processed into transcripts and subjected to content analysis. The transcripts were recorded and coded in Cantonese. The coded data were then translated into English. One method used in content analysis is to organise information from the text based on identified themes (Grbich, 2013). For this method, a system that codes the research themes must first be developed. The coding system is then used to code the transcripts to find the related information. The intelligent attributes and their scope, as discussed above, were used as the content of the coding system in this study. That means that any sentences discussing any of the intelligent attributes were coded and categorised according to which of the four key intelligent attributes was mentioned. This is a deductive analysis, as the codes were not generated from the data, but were drawn from existing literature (Hennink, Hutter, & Bailey, 2011). The coded data were used to determine the frequency with which each attribute was mentioned. Another concern of seniors was the technical requirements of SHT devices. The coded comments about each attribute were then grouped and categorised into a specific themes. Each specified theme was considered an indicator of the technical requirements of SHT, as recommended by seniors. Finally, a series of interviews with local experts and video-conferencing discussions with international experts in Australia, the UK and the USA who possessed rich knowledge and experience in smart home or building control system devices design, were used to review the 'intelligence' indicators of the smart home devices identified in this study.

Findings and discussions

Autonomy

The participants identified four indicators related to autonomy: *self-governing in special conditions, automatic off switches for safety, automatic functions for assisting physical and memory limitations,* and *automatic reminders*. Table 2 provides the coded comments for each indicator. The first indictor, self-governing in special conditions, was related to confidence in machines. The participants expressed worries about the occurrence of technical problems that they did not know how to fix. For example, the participants worried that the settings of the home control system might not automatically be saved or they might be required to re-set every command after a power cut. Therefore, seniors would have more confidence if the system was self-governing and functioned in any circumstances. The second indicator, automatic off switches, was related to seniors' concerns about home safety and security, particularly cooking safety. The participants indicated that they required SHT that contained a detector and controller for stoves. The third identified indicator was automatic functions for assisting physical and memory limitations. This indicator is related to the basic function of SHT – automation – and also implies that seniors understand the basic concept of SHT. According to the coded comments related to automation, SHT must address older people's physical and memory limitations. Automated doors (Fukui et al., 2010) and windows, for example, were suggested in the discussions. These automated systems can to improve accessibility for the older people, particularly those with poor functional ability. The automated doors and windows also help the older people achieve a higher level of independence. They are able to access/exit the buildings and open/shut the windows without assistance from others. Significantly, seniors wanted automation not because it was part of a trendy home, but because they wanted assistive devices. Therefore, stable and accurate performance is critical in technical designs for older people.

The fourth indicator in the autonomy attribute was automatic reminders. This indicator was related to the second indicator, but it has a reminding function rather than a controlling function. The second and fourth indicator can be combined by including a reminding function in the design of the safety detector and controller. Both sound and light can be used as alerting methods.

Table 2: Findings – Autonomy

Theme	Coded Participants' Comments
Self-governing in special conditions	A01: "Switching to a backup system automatically is required if there is any problem in the main system. B02: "Automatic switching to a backup system or backup electricity supply is needed when there is any interruption or problem in the electricity supply."

	F01: "Can the system recover by itself when it has a problem?" H02: "Will the system re-tune itself after a power cut?" H03: "Yes, older people would not know how to set up the system again after a power cut." H05: "…after a power cut. It is too complicated to contact a person to set up the system again." M04: "What should I do if there is a power cut? Do I have to reset everything when the system resumes?" N01: "I am afraid that these electronic devices will not function when the power is cut."
Automatic switches	A02: "It is good if the stove can turn off automatically when I leave the home." A06: "The main entrance of the home can be unlocked or opened (because it is connected to the home environment control system) if there is a fire or the electricity is cut." A06: "… the cooking stove can be turned off automatically if it is overheated." C01: "I prefer to use an electric stove … that has a timer (for setting an off time) … so that I do not need to worry about turning it off." D01: "A timer or automatic off switch function should be included in stoves." D02: "A safety function should be included to ensure the safety of cooking equipment, like automatic off functions for overheated equipment or long work times." E05: "The stove should be able to determine whether my pot is overheated and to turn it off automatically in such situations." H06: "I prefer to use cooking devices that turn off automatically." I02: "I prefer cooking devices that switch off automatically when something is overcooked." M06: "I will choose a stove that switches off automatically when it is overheated." N02: "Automatic heat detection or switching off functions of cooking devices are the most important features."
Automatic functions for	A02: "The kitchen and bathroom are the areas that need automation. For example, an automated switch with a sensor for lights, water tap, and

assisting with physical and memory limitations		cooking stove are useful for seniors when their memory is getting worse due to ageing."
	B03:	"I have installed an automatic switch for the lighting in the corridor of my home. I like this function."
	F02:	"It would be a good idea if there was a memory and detector installed in the fridge to record the storage of my fridge and tell me what is missing. It would be even better if the system could send the list of missing items to the supermarket.
	I01:	"I heard of a fridge that it is able to tell you what is inside. If you find you are missing something from the fridge, it is able to help you order through its connection to the Internet. This is very useful for the older people."
	N07:	"I want an automatic door and window at home."
Automatic reminder	F07:	"Users should be immediately informed if their heartbeat and blood pressure rate is high, so that they can stop or reduce their activities."
	G02:	"Sound or light reminders to turn on home appliances like air conditioners, kettles, stoves and washing machines are important."
	H02:	"Cooking devices could remind the users that they are on; an alarm could turn on every 15 minutes."
	K07:	"I prefer an alert that automatically reminds me to turn off devices, lock doors or bring keys with me when I am going out."

Controllability of complicated dynamics

Remote control, system flexibility, timer setting and *integrated system* were the indicators identified under the controllability of complicated dynamics attribute. Table 3 gives the coded comments made by the participants. First, remote control was considered important by a number of participants because it enhances the interactive operative functions of SHT. These comments indicated that most seniors have the technological skills to adopt new technical functions. The level of senior's technological capability was crucial information for the technical design of SHT devices. Second, system flexibility was mentioned in the discussions. Obviously, this requirement was raised by computer-literate participants. They wanted more flexible SHT devices or systems that could match their lifestyles. This suggests that flexible systems should be developed. Third, a number of participants suggested that timer settings would be helpful to reduce short-term memory problems, especially in the areas of medicine regimes and cooking safety. This indicator is similar to system flexibility but the scope is narrower. In addition, the notion of an automatic reminder was related to the autonomy attribute, especially in cooking safety. Therefore, a combined timer alert and automatic alert function installed in cooking devices would be an ideal way to provide cooking safety. Fourth, an integrated system should have a one-stop control system that connects all of the SHT devices in a home. Such an integrated system could also take the role of an information centre for seniors. The participants said that an integrated system would be a convenient way to control all of their home appliances. This requirement is important given the poor connections between individual SHT devices in current systems. A new approach that connects all of the installed devices in an individual home should be adopted in new SHT projects. This should reduce the cost of installing new devices in a new SHT project.

Table 3: Findings – Controllability of complicated dynamics

Theme	**Participants' Comments**
Remote controlling	A01: "Remote control function could be merged with mobile phone functions." L02: "Remote controls for home appliances that can be activated in-house and away from home would be very helpful to the older people." N07: "The remote control of home appliances when outside the home is a good design."
System flexibility	A05: "It is better to have the flexibility to add or remove any appliance from a 'one-stop-control' system." K01: "The home environment control system should allow users to choose which devices are controlled."
Timer setting	B02: "Assisting devices, like a medicine box, should allow users to set the time themselves to remind them when to take their medicine." D02: "A pre-set cooking function is necessary for cooking devices designed for the older people" F06: "I always rely on a timer when cooking." J01: "It would be good to have a timer installed in cooking devices." L03: "I usually set a timer to remind myself when I am making soup." M02: "I want a device that reminds me to take my medicine on time or I a device with a timer."
Integrated system	A02: "I look for a one-stop station that includes control and information of the home appliances." A03: "A one-stop control for building services. For example, one panel or button should be able to turn off all of the home appliances when leaving

		home.”
	F04:	“A one-stop control for all home appliances with a big control interface installed on the wall would be a good design for the older people.”
	I03:	“I prefer a one-stop-control system that allows the older people to control all of their home appliances.”

Man-machine interaction

The participants’ comments on the man-machine interaction attribute were grouped into three themes: *senior-friendly, voice control* and *reliability.* The coded comments related to these themes are presented in Table 4. First, senior-friendly was designated a core indicator of the man-machine interaction attribute. There are a number of issues related to making devices senior-friendly. The participants’ comments highlighted the fact that the technical needs of seniors and the kinds of assistance they require are different from those of younger people. A senior-friendly design should reduce the skills and training required to use the SHT devices. The comments in this section also highlighted the need to build seniors’ confidence in the use of technologies. The major design concerns of the participants focused on the interaction between the users and control panel/method, for example, issues such as font size on the control display. Second, some participants also commented on voice control. This is a new stage of human-machine interaction that provides an easier method of control for seniors and integrates ergonomic design and artificial emotion. In this study, it was treated as a technical requirement of SHT for seniors and it should be considered as an important stream in SHT development. Voice recognition systems would also be suitable for home security (Gregoriades et al., 2010). For example, a mobile and multi-modal human interface device for home automation system, named AppBlaster, was developed by the Hong Kong PHAB Association and the University of Hong Kong. This control device, developed under the Android platform, can feature with control functions including eye-ball tracking, touch screen and voice recognition (e.g. recognizing Cantonese) run on both smartphones and tablet computers (Office of the Government Chief Information Officer, 2016). However, the technology is still being developed, and is still not widely adopted in the community. Reliability was the third indicator in the man-machine interaction attribute, although only a small number of comments discussed the reliability of SHT directly. However, the reliability of the connections was a concern, which overlapped with the self-governing indicator under the autonomy attribute. In this study, reliability was designated as a technical requirement of SHT for seniors. There was one significant comment about IT security, shown in Table 4. SHT research and development should put more effort into IT security as well as the development of the functional features of SHT.

Table 4: Finding – Man-Machine Interaction

Theme	Participants' Comments
Elderly-friendly	A04: "The design and use should be simple and senior-friendly."
	A06: "It is hard for us to even press a button when we are getting older. So, less interaction with the machine or system would be a good idea for the older people who are losing their physical functions."
	B01: "…the design should be simple for the older people and should give them confidence about their use of smart-home-technology devices."
	B02: "The figure or words on the all of the home appliances … should be big enough for the older people to read. Fewer words on the appliances is preferred."
	D03: "Cooking device designs should be user-friendly and simple, like just pressing one to two buttons when giving an order."
	F03: "I care about whether I know how to operate the appliances/devices when they are too smart."
	F05: "I wish that smart-home-technology devices were user-friendly and easy to learn."
	F08: "The devices should be easy to use, should not be complicated.
	H01: "The design of smart-home-technology devices should be simple, and easy to control."
	J02: "The display/interface of the control panel should use big figures to indicate the function. Fewer words are preferred."
	N02: "The control of the devices should be easy and direct."
Voice controlling	G2: "Voice control would be a good idea for home appliances. The control would be easy."
	J03: "Voice control is a good idea."
Reliability	I02: "I worry that hackers will be able to control my home appliances."
	K01: "If there is a remote control system, I would worry whether it was really off."

Bio-inspired behaviour

Suitable for built environment, biological adaptation and learning and *human-like* were identified as the three indicators under the attribute of bio-inspired behaviour. Table 5 presents the coded comments related to these indicators. The first indicator, suitable for built environments, reflects the participants' concerns about adapting SHT to their existing home environment. In fact, the foundation and condition of most home environments are not appropriate for SHT devices and system installation. In this regard, there needs to be more investigation into how SHT devices can be incorporated into existing, especially high density environments. Clearly, home environments vary among countries and regions. Therefore, localised data are needed so that solutions can be developed for different conditions. The second indicator, biological adaptation and learning, emerged mainly from discussions of an infrared fall-detecting system. A number of participants expressed worries about faulty alarms, as their living habits and postures are complicated. For example, when a person is cleaning the floor, his body is close to floor level, but this does not mean he has fallen. A system should be able to learn the individual biological characteristics of the users. In addition, comprehensive data on biological features should be installed in such SHT systems. An accurate evaluation of biological features would give seniors confidence in their SHT systems. The third indicator, human-like behaviour, emerged from interesting discussions of assistive robots. Some participants preferred a robot as their assistive equipment because of its human-like features, for example emotions. In addition, an assistive robot was expected to provide all-round help to older people. This aligns with the requirements of an integrated system under the controllability of complicated dynamics attribute. The use of robots in our daily lives is still a relative new idea and their development is still in an early stage, for example, robot systems for feeding disabled people (Song et al., 2010). Nevertheless, the findings suggest that some seniors would accept this innovative technology and in fact look forward to using it in the future.

Table 5: Findings – Bio-inspired behaviour

Theme	Participants' Comments	
Suitable for built environment	A01:	"Does the installation suit the existing home environment? … Is there enough space for the machine?"
	A01:	"Do I have to purchase a new stove to match the system if I wish to install the cooking safety control? Is this system applicable to both gas and electric stoves?"
	B02:	"The smart-home-technology appliances should be pre-installed in new flats so that they are adapted to the built environment."
	G04:	"The design should adapt to existing home settings because the existing environment is not usually designed for seniors."
Biological	E03:	"The system (infrared fall detecting system) should be smart

adaption and learning		enough to detect whether I am in emergency or just cleaning the floor or near the floor level. The system should be accurate and learn our living habits."
	G01:	"I worry that the system (infrared fall detecting system) would set off a false alarm easily if it does not understand my living habits."
	I04:	"How does the system (infrared fall detecting system) judge whether users have fallen down?"
	L01:	"I worry that it (infrared fall detecting system) will give many false alarms because of the variety of behaviour and habits in different people."
	M04:	"I would consider the learning ability of the system (infrared fall detecting system). The system should learn the user's behaviour, habits, and home environment in a comprehensive way."
	N05:	"I also doubt how the system will judge whether the users need help or are in an emergency situation."
	N08:	"I doubt its accuracy in detecting human habits and postures."
Human-like behaviour	J01:	"I want a robot that can talk to me like my son and look like a human. I hope the robot can communicate with me and console me when I am depressed."
	J09:	"I want a robot that can help me finish all of the house and cleaning chores."
	N08:	"They should be a like humans to remind seniors to take their medicine on time, the type of medicine, and the volume of medicine. It would be good if the system made reminders in a way that was like human interaction."

Conclusions

The aging population has emerged as one of the most pressing social, economic and political challenges in the world today, and one that many countries can no longer disregard (World Health Organization, 2011). In particular, care for the older adults generates a significant burden through the costs and stress placed on family, caregivers and the community in general. The needs of the new generation of ageing people are changing and technological aids keep improving. This study explored the functionalities and attributes of SHT devices that support the 'ageing in place' of seniors in Hong Kong. Fourteen indicators of the technical requirements for SHT devices for seniors in high density living environments, based on four key intelligent attributes developed by Bien et al. (2002), were identified. Some of these indicators are similar to traditional SHT technical features, such as automation, and some are innovative, such as developing human-like behaviour in robots or control systems. Those indicators suggest promising directions for the technical development of SHT designed to sustain ageing in place. The ultimate purpose of these technical improvements is to open the silver market and increase the penetration of SHT. SHT would then be able to help ageing people, society and also the business sector.

The knowledge acquired in this study should inform future SHT design so that the technology is more universally usable for older adults. The study provides significant information on the design options of SHT targeted at seniors. Appropriate technological intervention will generate a 'win-win' situation for seniors, caregivers, the community and the government by enhancing the independence of older people and reducing the burden and distress of the caregivers. In terms of economic effect, a better understanding of SHT requirements helps to develop a strong SHT-related market and job opportunities for the product design and healthcare sectors. By investigating the optimal intelligence functionalities and capacities of SHT systems for seniors, this study provides insights for building services engineers and product designers. This study is also of international importance, as the knowledge and approach generated can be extended beyond Hong Kong to other countries.

One limitation of this study is the narrow group of seniors in the sample population. Further studies should involve larger samples with a wider range of physical and cognitive disabilities. Also, the features identified in this study need to be further developed into 'smart' performance measures of the SHT devices and systems. This study will be extended by adopting the fuzzy analytic network process (FANP) approach to identify the functionalities and capacities of SHT that are optimal for improving the AIP/QoL of seniors. A more systematic and structured approach will be adopted to evaluate the ability and components of smart home devices required to fulfil QoL and AIP requirements. Such a study will provide a benchmark to compare the system performance of different devices in subsequent studies.

Acknowledgements

This study was supported by the Hong Kong Polytechnic University [Grant No. G-YBCE]. The authors also gratefully acknowledge the support and generosity of the Institute of Active Ageing (IAA) of the Hong Kong Polytechnic University and the Hong Kong Housing Society (HKHS), without which the present study could not have been completed.

References

Arditi, D., Mangano, G., & Marco, A. D. (2015). Assessing the smartness of buildings. *Facilities, 33*(9/10), 553-572. DOI: http://dx.doi.org/10.1108/F-10-2013-0076

Australian Bureau of Statistics. (2015). *Regional Population Growth, Australia, 2013-14: Victoria*. Retrieved from Australian Bureau of Statistics, Australia Government website: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/3218.0Main%20Features252013-14?opendocument&tabname=Summary&prodno=3218.0&issue=2013-14&num=&view=

Bálint, L. (1995). People and computers - human centred approaches to computer integration in manufacturing adaptive human-computer interfaces for man-machine interaction in computer-integrated systems. *Computer Integrated Manufacturing Systems, 8*(2), 133-142.

Bank of America Merrill Lynch. (2014). *Thematic Investing: The Silver Dollar - Longevity Revolution Primer*. Retrieved from http://ec.europa.eu/research/innovation-union/pdf/active-healthy-ageing/merrill.pdf#view=fit&pagemode=none

Beevis, D., & Slade, I. M. (2003). Ergonomics—costs and benefits. *Applied Ergonomics, 34*(5), 413-418. DOI: 10.1016/S0003-6870(03)00061-9

Bien, Z., Bang, W.-C., Kim, D.-Y., & Han, J.-S. (2002). Machine intelligence quotient: Its measurements and applications. *Fuzzy Sets and Systems, 127*(1), 3-16. DOI: 10.1016/S0165-0114(01)00149-X

Cañamero, L. (2005). Emotion understanding from the perspective of autonomous robots research. *Neural Networks, 18*(4), 445-455. DOI: 10.1016/j.neunet.2005.03.003

Census and Statistics Department. (2016). *Thematic Household Survey Report No. 59: Pattern of Smoking/Personal Computer and Internet Penetration/Use of Language*. Retrieved from Census and Statistics Department, Hong Kong SAR Government website: http://www.statistics.gov.hk/pub/B11302592016XXXXB0100.pdf

Chen, C. K., Shie, A. J., Wang, K. M., & Yu, C. H. (2015). An ageing-in-place service innovation model by using TRIZ methodology. *Human Factors and Ergonomics in Manufacturing & Service Industries, 25*(2), 166-182. DOI: 10.1002/hfm.20536

Dewsbury, G., Taylor, B. & Edge, M. (2001). Designing safe smart home systems for vulnerable people, Proceedings of The First Dependability IRC Workshop, Edinburgh, October 2001. DOI: 10.1.1.16.5138

Eitner, C., Enste, P., Naegele, G., & Leve, V. (2011). The discovery and development of the silver market in Germany. In F. Kohlbacher & C. Herstatt (Eds.), *The Silver Market Phenomenon: Marketing and Innovation in the Aging Society* (pp. 309-324). Berlin: Springer. DOI: 10.1007/978-3-642-14338-0

Elsenpeter, R. C., & Velte, T. J. (2003). *Build Your Own Smart Home*. New York: McGraw-Hill. ISBN: 0072253770

Farrell, J., Berger, T., & Appleby, B. D. (1993). Using learning techniques to accommodate unanticipated faults. *IEEE Control Systems, 13*(3), 40-49.

Floreano, D., & Mondada, F. (1998). Evolutionary neurocontrollers for autonomous mobile robots. *Neural Networks, 11*(7–8), 1461-1478. DOI: 10.1016/S0893-6080(98)00082-3

Fogel, B. S. (1992). Psychological aspects of staying at home. *Generations, 16*(2), 15.

Fukui, R., Kadowaki, K., Noguchi, H., Mori, T., & Sato, T. (2010). A supplementary automatic door device for hybrid support of humans and robots. In Y. Lee, Z. Z. Bien, M. Mokhtari, J. T. Kim, M. Park, J. Kim, H. Lee, & I. Khalil (Eds.), *Aging Friendly Technology for Health and Independence: 8th International Conference on Smart Homes and Health Telematic, ICOST 2010, Seoul, Korea, June 22-24, 2010. Proceedings* (pp. 1-8). Berlin, Heidelberg: Springer. DOI: 10.1007/978-3-642-13778-5_1

Goodwin, S. (2013). *Smart Home Automation with Linux and Raspberry Pi* (2nd ed.). Berkeley: Apress. ISBN: 9781430258889

Grbich, C. (2013). *Qualitative Data Analysis : An Introduction* (2nd ed.). London: SAGE. ISBN: 9781446202975

Gregoriades, A., Obadan, S., Michael, H., Papadopoulou, V., & Michael, D. (2010). A robotic system for home security enhancement. In Y. Lee, Z. Z. Bien, M. Mokhtari, J. T. Kim, M. Park, J. Kim, H. Lee, & I. Khalil (Eds.), *Aging Friendly Technology for Health and Independence: 8th International Conference on Smart Homes and Health Telematics, ICOST 2010, Seoul, Korea, June 22-24, 2010. Proceedings* (pp. 43-52). Berlin, Heidelberg: Springer. DOI: 10.1007/978-3-642-13778-5_6

Hennink, M., Hutter, I., & Bailey, A. (2011). *Qualitative Research Methods*. London: Sage Publications. ISBN: 9781412922265.

Holroyd, P., Watten, P., & Newbury, P. (2010). Why is My Home Not Smart? In Y. Lee, Z. Z. Bien, M. Mokhtari, J. T. Kim, M. Park, J. Kim, H. Lee, & I. Khalil (Eds.), *Aging Friendly Technology for Health and Independence: 8th International Conference on Smart Homes and Health Telematic, ICOST 2010, Seoul, Korea, June 22-24, 2010* (pp. 53-59). Berlin, Heidelberg: Springer. DOI: 10.1007/978-3-642-13778-5

Information Services Department. (2015). *Hong Kong: The Facts: Population*. Retrieved from GovHK, Hong Kong SAR Government website: http://www.gov.hk/en/about/abouthk/factsheets/docs/population.pdf

Information Services Department. (2016). *Speech by Financial Secretary at Joint Business Community Budget Speech Luncheon*. Retrieved from HKSAR Government website: http://www.info.gov.hk/gia/general/201603/16/P201603160585.htm

Kitzinger, J. (1994). The methodology of focus groups: The importance of interaction between research participants. *Sociology of Health & Illness, 16*(1), 103-121. DOI: 10.1111/1467-9566.ep11347023

Kohlbacher, F., & Hang, C. C. (2011). Applying the disruptive innovation framework to the silver market. *Ageing International, 36*(1), 82-101. DOI: 10.1007/s12126-010-9076-x

Liamputtong, P. (2011). *Focus Group Methodology: Principle and Practice*. London: SAGE. DOI: http://dx.doi.org/10.4135/9781473957657

Liu, J., Jin, X., & Tsui, K. C. (2005). *Autonomy Oriented Computing from Problem Solving to Complex Systems Modelling*. New York: Kluwer Academic. ISBN: 9781402081224

McFarland, D., & Bösser, T. (1993). *Intelligent Behavior in Animals and Robots*. MIT Press/Bradford Books, Cambridge, MA. ISBN: 9780262515436

Office of the Government Chief Information Officer (2016), *Development of Assistive Technologies for Persons with Disabilities*, Retrieved from http://www.ogcio.gov.hk/en/community/disabilities/

Organisation for Economic Co-Operation and Development. (2015). *G20 Workshop On "Silver Economy" and Ageing Soceity: An Opportunity For Growht and Job Creation in the G20 Countries*. Retrieved from http://www.g20ewg.org/index.php/component/phocadownload/category/34-side-events?download=121:silver-economy-and-ageing-society-an-opportunity-for-growth-and-job-creation-in-the-g20-countries-oecd

Rubinstein, R. L. (2002). The Thrid Age. In R. S. Weiss & S. A. Bass (Eds.), *Challenges of the Third Age: Meaning and Purpose in Later Life* (pp. 29-40). Oxford: Oxford University Press. ISBN: 9780195150254.

Song, W.-K., Kim, J., An, K.-O., Lee, I.-H., Song, W.-J., Lee, B.-S., . . . Lee, E.-C. (2010). Design of novel feeding robot for Korean food. In Y. Lee, Z. Z. Bien, M. Mokhtari, J. T. Kim, M. Park, J. Kim, H. Lee, & I. Khalil (Eds.), *Aging Friendly Technology for Health and Independence: 8th International Conference on Smart Homes and Health Telematics, icost 2010, Seoul, Korea, June 22-24, 2010. Proceedings* (pp. 152-159). Berlin, Heidelberg: Springer. DOI: 10.1007/978-3-642-13778-5

Statistics Canada. (2016). *Focus on Geography Series, 2011 Census: Census Metropolitan Area of Vancouver, British Columbia*. Retrieved from Statistics Canada, Canada Government website: https://www12.statcan.gc.ca/census-recensement/2011/as-sa/fogs-spg/Facts-cma-eng.cfm?LANG=Eng&GK=CMA&GC=933

Tempest, S., Barnatt, C., & Coupland, C. (2011). Grey power: Developing older customer strategies. In F. Kohlbacher & C. Herstatt (Eds.), *The Silver Market Phenomenon: Marketing and Innovation in the Aging Society* (pp. 203-216). Berlin, Heidelberg: Springer. DOI: 10.1007/978-3-642-14338-0_15

Teuscher, C., Mange, D., Stauffer, A., & Tempesti, G. (2003). Bio-inspired computing tissues: Towards machines that evolve, grow, and learn. *Biosystems, 68*(2–3), 235-244. DOI: 10.1016/S0303-2647(02)00100-4

The World Bank. (2016). *Population Ages 65 And Above (% of total)*. Retrieved from http://databank.worldbank.org/data/reports.aspx?source=2&country=&series=SP.POP.65UP.TO.ZS&period=

van Der Vyver, J. J., Christen, M., Stoop, N., Ott, T., Steeb, W. H., & Stoop, R. (2004). Towards genuine machine autonomy. *Robotics and Autonomous Systems, 46*(3), 151-157. DOI: 10.1016/j.robot.2004.01.002

Weiss, R. S., & Bass, S. A. (2002). *Challenges of the Third Age: Meaning and Purpose in Later Life*. Oxford: Oxford University Press. ISBN: 9780195150254.

Wong, J. K. W. (2007). *Development of Selection Evaluation and System Intelligence Analytic Models for the Intelligent Building Control Systems.* (PhD Thesis), Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong.

Wong, J. K. W., Li, H., & Lai, J. (2008). Evaluating the system intelligence of the intelligent building systems: Part 1: Development of key intelligent indicators and conceptual analytical framework. *Automation in Construction, 17*(3), 284-302. DOI: 10.1016/j.autcon.2007.06.002