Home as a Platform: Levels of Automation for Connected Home Services

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Abstract. Tomorrow's home will not only be a place to live, but will be a platform of services and experiences provided by an interconnected ecosystem of technologies. This platform requires a framework that describes and simplifies the types of homes and services which address consumers' needs and provides current and future directions for researchers and practitioners. Although there have been some efforts to understand homes' types and levels of automation, there is not a commonly established framework. In this paper, we propose a framework outlining types of homes and various levels of home automation: Electric homes, Customized homes, Proactive homes, Support homes, and Companion homes. This framework is built upon previous automation models and is supported by our expert interview panel. The first two levels describe current states and the next three levels discuss future directions and possibilities. Each level varies in terms of the complexity and intelligence of in-home technologies, their interaction and integration with one another as well as with the user, ability to process information based on the stages from information processing theory, and aspects of companionship that a home can provide to its residents. The proposed framework is the first step in achieving a standardized understanding of home automation across stakeholders.

Keywords: Smart home · Automation · Taxonomy

1 Introduction

The world population is aging. Based on [1], by 2050, there will be around 2 billion older adults; a high percentage of them may have conditions that require support and care. Among older adults, aging in place is the preferred lifestyle [2, 3] where they stay in their own homes and communities rather than making a move to an institutional setting. With such growth and demand from those that spend most of their time in their homes alone [4, 5], there is now a greater desire for homes that enable a diversity of activities and to accommodate various capabilities and needs.

New and emerging technologies are well positioned to assist in providing the desired care and support in homes; to enable connection from the home to the outside community; to make jobs convenient and accessible within and around the home; and to maximize residents' independence, as well as to support their caregivers. However, the state of home technologies and services is fragmented with no standard structure for stakeholders to easily access and utilize.

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In other domains, such as surface transportation and aviation, standards and taxonomies are in place to define the various levels of automation, as well as the related degrees of human vs. system involvement in a given task. For example, SAE International has defined levels of vehicle automation, from no automation to full automation, to describe and categorize varied levels of human vs. system involvement in the driving task, as well as to classify existing in-vehicle technologies [6]. This framework is widely accepted among industry, academia as well as the public sector and utilized to guide designing, testing and regulating self-driving technologies.

In the areas of smart and connected homes [7–11] and automation [12, 13], there have been efforts to define levels of automation and to create a taxonomy. However, there is not a clear framework on types of homes and levels of automation that stakeholders across different roles and objectives agree on [14]. Moreover, previous efforts have not provided a cohesive model of homes that allows designers and researchers to identify a home's automation level with a user-centered perspective. In other words, most of the existing models focus on in-home technologies as opposed to the home as a platform and user interaction with it. This paper aims at bringing attention to the absence of a framework for levels of automation in homes. The proposed framework is an expansion of the current models in the area of automation to address this question: How can we classify homes and their levels of automation from user-centered perspective? To this end, an in-depth literature review revealed several necessary elements for this framework. Literature from the fields of robotic automation was reviewed to develop a coherent understanding of human-automation interaction. The elements from the previous research on automation were synthesized into a framework that can serve as a tool for designers in identifying the appropriate automation level of a home and to facilitate communications between stakeholders and to enable easier access by consumers. We believe that having a standard definition of home technologies and services, along with a structure to describe the varied levels of automation, can open the horizon to guide future developments and discussions.

2 Defining the Smart Home

Smart homes have been defined mostly as residences augmented with technologies that are built to enhance residents' lifestyle through promoting independence and human-friendly control, comfort, and security while reducing living and care costs [11, 15–17], and responding to the household needs [7, 18].

Recently, Li et al. [19] discussed three generations of smart home technologies:

1. Wireless technology and proxy server home automation approach: This is the first generation of smart home technologies. These technologies were designed to monitor activities in the home and operate electrical devices through Bluetooth, ZigBee, etc.
2. Artificial intelligence controlled electrical devices: The second generation of smart home technologies evolved to the idea of Smart Home Environments (SHE). Unless the first generation that devices were operated based on predefined programs, artificial intelligence, multi-agent systems, and automation run SHE.

3. Robots: The integration of robotics with artificial intelligence differentiates the third generation of smart home technologies from the second generation. These robots can recognize and respond to people's needs through different interaction modalities. Their benefit over the second generation's devices is that they can create a relationship with humans.

3 What Should Be Automated?

The home is a complex domain where multiple activities and tasks take place in various places with different characteristics. The ability to live independently requires the performance of a range of activities. Previous studies on aging in place, ambient assisted living, and helping older adults live independently focused on some activities that are core aspects of everyone's daily life. Based on [20] these activities are categorized as follows:

1. Activities of Daily Living (ADLs): basic tasks that people normally do without any assistance. These activities are eating, bathing, dressing, toileting, transferring, and walking.
2. Instrumental Activities of Daily Living (IADLs): require more complex thinking skills and are essential for people to function in their communities independently. Cooking, driving, using telephone or computer, shopping, keeping track of finance, managing medication, doing laundry, and housekeeping are considered as IADLs.

ADLs and IADLs have been used in many studies. For example, [21] studied detecting ADLs using wearable and non-wearable sensors through different machine learning algorithms. This study was an attempt to create an ambient assisted living environment for older adults to age in place. These efforts are valuable in demonstrating technological capabilities and potential applications. However, based on the varieties of tasks that people accomplish in their homes,, automation should be considered in its context and in regards to holistic user needs, rather than automating every single task within the home. Therefore, instead of moving towards automating all in-home tasks and eliminating the roles of users, technology should be designed in a way to optimize users' experience based on their needs.

4 Understanding Levels of Automation

Automation has been made more affordable recently through the advancement of technology and implementation of IoT and ICT (information and communications technology). Parasuraman et al. [13] defined automation as "the full or partial replacement of a function previously carried out by the human operator" and tried to answer this question: given the technical capabilities, which system functions should be automated and to what extent? In response, they outlined a model of human interaction with automation which was the extension of previous model on levels of automation [22, 23]. In the previous models, a continuum of levels was defined from the lowest level of fully manual performance to the highest level of full automation.

Levels of automation of decision and action selection
10. The computer decides everything, acts autonomously, ignoring the human
9. Informs the human only of it, the computer, decides to
8. Executes automatically, then necessarily informs the human, and
7. Allows the human restricted time to veto before automatic execution, or
6. Executes that suggestion of the human approves, or
5. Suggests one alternative
4. Narrows the selection down to a few, or
3. The computer offers a complete set of decision/action alternatives, or
2. The computer offers no assistance, human must take all decisions and actions
1. The computer offers no assistance, human must take all decisions and actions

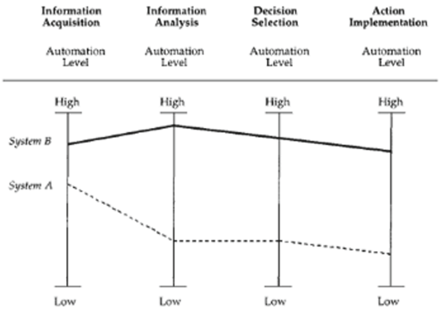

Fig. 1. Models of levels of automation (left) [22, 23] vs. (right) [13].

Therefore, the concept of "levels of automation" addresses this continuum from manual to full automation that have been divided into ten [13], eight, and four levels [24] in previous studies. The model suggested by [13] describes four stages of human information processing: 1. information acquisition, 2. information analysis, 3. decision and action selection, 4. action implementation, In this model, input functions (information acquisition and information analysis) that come before decision making process were considered in the continuum. While in the previous models only automation of decision and action selection, or output functions of a system, were explained. They explained: "the automation can differ in type and complexity, from simply organizing the information sources, to integrating them in some summary fashion, to suggesting decision options that best match the incoming information, or even to carry out the necessary action." Based on their view, each of the functions (i.e., stages of information processing) can be automated with various degrees and a system can involve automation of all four functions at different levels. Figure. 1 also shows a 10-point scale of levels of automation, with higher levels representing increased automation of computer over human action [22, 23].

The model described in [13] also suggests that each stage in the model of human information processing has its equivalent in system functions that can be automated. Similar efforts have been seen in other studies [24, 25]. For example, the framework of robot autonomy described by [25] autonomy as "the extent to which a robot can sense its environment, plan based on that environment, and act upon that environment with the intent of reaching some task-specific goal without external control." In this definition, sense, plan, and act refer to the functions from human information processing theory. Table 1 shows the four functions, equivalent automation dimension in a system and a brief explanation.

Table 1. This table shows mapping the four stages of information processing with automation dimensions from [13]

Functions	Automation dimensions	Explanations
Information processing	*Acquisition Automation*	Sensing and registration of input data (raw data)
Information Analysis	*Analysis Automation*	Deriving a list of options through analysis, trend prediction, interpretation, prediction and integration
Decision and action selection	*Decision Automation*	Selection from among decision alternatives and recommend courses of action
Action implementation	*Action Automation*	Execution or authority to act on the chosen option

To avoid treating the model as a static formula and as an iterative method to identify potential design issues, [13] considered primary and secondary evaluative criteria in deciding what type and level of automation should be given to a system. Primary evaluative criteria evaluates consequences for human operator performance (mental workload, situation awareness, complacency, and skill degradation) after automation has been implemented. Secondary evaluative criteria, covers automation reliability and costs of decision/action outcomes. Automation reliability is an important factor in user trust and consequently human use of automated systems. In addition, costs of decisions and associated actions that humans and automated systems take in most systems vary.

5 Method

The proposed framework in this paper is built on the taxonomies and models describing levels of automation [12, 13]. However, this suggested framework includes some key changes and additions to the way which automation should be conceptualized for homes. First, we highlight the importance of home as a whole rather than focusing on tasks and in-home technologies. This factor is important in this framework because with the interoperability and interconnectedness of the emerging systems in the homes, considering tasks and devices alone and apart from the ecosystem of the home is neither helpful nor in line with the current directions. Second, some of the determinant factors to define the levels are variables that are meaningful to this topic. In other words, applying all the key factors from the previous model was not practical. Third, home is a complex and dynamic environment where the number and types of users are unlimited. Although this taxonomy was an effort to simplify the concept for the bigger picture and outlining future directions, automation in each level may change depending on the resident(s), task, and interaction over time.

Besides the in-depth literature review and borrowing concepts and models from the previous studies, this model was discussed and validated in a meeting with experts from different backgrounds. In this meeting, seven experts from different companies involved in the MIT AgeLab's C3 Connected Home Logistics Consortium were presented the framework and the logic behind it. The goal of this consortium is to understand home as a platform with the focus on three main concepts: care, convenience, and connectivity. After the presentation, the framework was discussed in detail. Questions and concerns were explored and the framework, and possible next steps were discussed to validate the framework with more data.

6 Toward a Framework for Levels of Home Automation and Home Taxonomy

The suggested taxonomy is an effort to provide a platform for researchers to discuss the current status of home automation and smart homes, as well as clarifying some perspective of possible future directions and goals. Moreover, this taxonomy is intended to help standardize terminology, instead of using a variety of similar languages such as smart homes, intelligent homes, home networks, home automation, connected living and so on. While stakeholders today are using different vocabularies for similar features and functions in their products, our proposed taxonomy aims to facilitate communication among researchers, designers, and developers which consequently can improve consumers' understanding of the products.

In addition, as is happening in the area of transportation, the taxonomy provides a platform for policymakers. For example, we expect that in near future, sensors and in-home devices that can track people's activities, vital signs, and any abnormal changes. The benefit will be that all these abnormalities, whether minor or major, will be detected and treated in early stages. A related concern, however, can be stated around the potential for related information to be shared with different parties, and also around safeguarding against potential threats to privacy. As policymakers approach regulating how data may be collected, processed, and shared, the proposed framework can help guide the understanding around technical capabilities and interconnectedness of various technologies.

The suggested taxonomy (see Fig. 2) is an effort to address the above concerns. Five levels have been identified and defined in this taxonomy: Electric homes, Customized homes, Proactive homes, Support homes, and Companion homes. Each level is identified based on types of in-home devices, their capabilities in understanding users in terms of receiving information, processing data, decision making, action, human involvement, and user controls.

6.1 Electric Homes

Electric homes describe the majority of homes around the world. These homes are not a platform yet since there is not a central system that can connect and coordinate the tasks and the needs. Results of the discussion with the experts during the meeting showed that everyone agrees on the definition and determinant criteria for this level. Electric homes are described by the following characteristics:

- All the in-home technologies run with pre-determined functions (excluding universal controllers such as smartphone and computer). The pre-determined functions are the default or options that can be selected by users to achieve certain goals.

The available options and functions are the same for all users. In other words, there is no technology with the ability to learn from users and adapt to their needs in electric homes.
- Considering the information processing theory for the levels of automation of devices in electric homes, all the devices can only receive information at the highest level (sense, interpret, decide, and act), and act upon that (stimulus-action response). Stages like interpreting data, making predictions and decisions, and higher-level data processing are missing in this category.
- In-home technologies are not connected with each other. These in-home devices exist in a vacuum. Each performs its function by itself, and all require a high level of human involvement.
- Electric homes do not understand resident needs and/or act upon that. There is no awareness of users, their habits, status, and activities.

6.2 Customized Homes

Customized homes have been adopted vastly during the last decade. Recent smart technologies in many of the homes nowadays, changed user behavior, routine, and the way they interact with in-home technologies. New features like voice recognition systems, or remote controls through apps helped residents to save time and costs. The validated determinant criteria after our discussion with the experts showed that in a customized home:

- There is at least one technology in the home (excluding the universal controllers such as smartphone and computer) that runs with programmable instructions. This technology should be able to learn from the users and adapt to their needs. Users can customize the device to address their needs but still there is a high level of user involvement.
- Considering the information processing theory for the levels of automation of devices in electric homes, devices can autonomously receive information, make decisions and act. However, devices are limited in terms of memory, the types of jobs they can accomplish, and the complexity of data processing and decision making.
- Technologies may be connected with one another, but connection is not a requirement.
- Customized homes have a limited understanding of user needs.

6.3 Proactive Homes

Based on [13], adaptive automation is referring to a flexible level of automation across any of the four stages of automation function dimensions. The level (low to high) and types of automation (acquisition automation, analysis automation, decision automation, action automation) could be designed to vary depending on situational demands during operational use. This context-dependent automation is a concept that was borrowed and applied to the 3rd to 5th level of our taxonomy. Basically, with the capabilities of an adoptive automation system and interoperability and interconnection of in-home devices, the home will be considered as a platform with the below criteria:

- All of the in-home technologies run with a central AI. The central AI receives and processes all the information, makes decisions, and acts if necessary (the same level of information processing as humans). This central AI may be a social robot, a router, a software on a mobile device, or in the cloud, but most of the in-home technologies in the home has to talk to each other through it.
- The intelligence and complexity of each in-home technology does not matter as long as all of them are connected to and being run through the central AI. The central AI manages the in-home activities and requires only a moderate amount of user involvement for managing in home tasks.
- In-home technologies are connected with each other through the central AI.
- Proactive homes understand the residents' needs and/or can act upon them. Homes are aware of users, their habits, status, and activities.
- Proactive homes are connected to other residences and their surrounding communities to increase efficiency of services.

6.4 Support Homes

With the application of context-dependent automation described in level 3, support homes may be even further in the future where technology with the capability of dealing with more complex data like emotions and affect can exceed human intelligence. In these homes:

- All the in-home technologies run with a central AI. The central AI receives and processes all the information, makes decisions, and acts if necessary. The central AI has a higher-level capability of information processing than humans. For example, it can receive and analyze types and ranges of data that human sensory system is limited to receive those. This central AI may be a social robot, a router, a software on a mobile device, or in the cloud, but most of the in-home technologies in the home has to talk to through the central AI.
- The intelligence of each in-home technology does not matter as long as all of them are connected and being run through the central AI. The central AI manages the in-home activities and the level of user involvement in managing in-home tasks is low.
- In-home technologies are connected with each other through the central AI.
- In-home technologies are connected to users and their needs. Homes are aware of users, their habits, status, and activities. They understand users, their emotions, and needs better than themselves. They can make better decisions, provide better options, and act upon them.
- Support homes are connected to other residences and their surrounding communities to increase efficiency of services.

What discriminates level 3 and 4 is the central AI's ability to understand human needs and to adapt. Although homes in both levels have a clear image of users, their routines and behaviors, level 4 is associated with superior abilities in decision making and prediction abilities particularly in complex situations such as residents' emotional needs and affective states.

6.5 Companion Homes

Companion homes have all the capabilities of proactive or support homes but also include the following characteristics:

- In companion homes, there is one or more physical entity that can manage all physical tasks and chores. The physical entity could be built into the in-home technologies or a separate entity like a social robot. This physical entity provides companionship to the residents that go beyond basic functionalities. This companionship encompasses social and emotional aspects.
- The central AI can be built into the physical entity or separately but they should be connected with each other.

Home Levels of Autonomy	Electric Home	Customized Home	Proactive Home	Support Home	Companion Home
Devices with predetermined functions	○	○	○	○	○
Devices with learning and adaptive capabilities		○	○	○	○
Connection to Smart City			○	○	○
Central AI with the same level of human information processing			○	○	○
Central AI with superior level of human information processing				○	○
Physical companion					○
Human Involvement	High	High	Moderate	Low	Not Required

Fig. 2. A summary of the home taxonomy and levels of automation

Results of our conversations with the experts showed some concerns around the level of human involvement in many of the tasks in homes belong to level 3, 4, and 5 which need to be explored by users in the next steps.

7 Discussion and Conclusion

Home is a complex environment. It is private and shared at the same time. There has been a huge amount of efforts during the last century to make homes more convenient for the residents through different ways. Among all the efforts, in-home technologies have played an important role in changing the layout of the homes, its dynamic, and residents' lifestyle.

With the emergence of IoT and ICT, home automation and smart home technologies have been investigated widely [26]. Assistive technologies, health management systems, safety tools and sensors, communication devices, and energy systems are some examples of the efforts to increase safety, security, and convenience and overall improve residents' lifestyle [30].

Although there has been research in understanding user needs and describing models that can describe smart home technologies, there is no clear framework on types of homes and levels of automation that various stakeholders agree on. In this paper, we proposed a taxonomy outlining various levels of homes automation. This taxonomy describes five types of homes and levels of home automation: Electric homes, Customized homes, Proactive homes, Support homes, and Companion homes. The first two levels describe the current homes and the next three levels discuss the future directions and possibilities.

The highest level in this taxonomy opens discussions and research topics on the area of home as a companion which is capable of satisfying user needs in many dimensions: emotionally, socially, and physically. Each level varies in terms of the complexity and intelligence of in-home technologies, their interaction and integration with one another as well as with the user, home's ability in processing information based on the stages from information processing theory, and aspects of companionship that a home can provide to residents. These determinative factors of levels were selected based on their impact on user mental model. For example, one study examined how different smart home abstractions, priming, and user expectations affect end users' mental models of a hypothetical system [27]. They found that different degrees of system personification (unmediated and agent-mediated) and capabilities (data and devices) influence user interaction with the smart home. They showed that when participants were presented with the unmediated devices abstraction, participants did not assume any connections among the devices.

Results of the MIT AgeLab C3 Connected Home Logistics Consortium expert meeting helped us to understand the application of this framework from different aspects and opened new questions. For example, how much different technologies such as safety and security systems, health systems, assistive devices, social robots, energy systems, housework assistants, and entertainment systems with different capabilities of automation and interoperability in different levels influence user interaction with them and the home and what are the consequences in terms of user trust, preference, frustration, changes in their lifestyle?

As Parasuraman et al. [13] said, "automation design is not an exact science. However, neither does it belong in the realm of the creative arts, with successful design dependent upon the vision and brilliance of individual creative designers." Having a framework that can provide guidance about all facets of a concept is necessary. Although frameworks simplify the concepts and presents an abstract view of a complex idea, they help researchers to situate plans around ideas that are well-grounded in the literature.

The proposed framework is the first step in achieving a standardized understanding of home automation across stakeholders. This framework has been developed with a user-centered perspective and is intended to be used as a reference for designers and researchers in the area of developing smart homes and in-home technologies and products. The taxonomy can also be utilized as a foundation for understanding relationships between people's activities and technological solutions. Future studies need to address how we can improve our current homes (Electric and Customized homes) as they evolve into a more convenient, connected and caring platform. What aspects of users' mental models should we consider to help design the central AI system for highly automated homes? What factors should be addressed when we talk about specific users, e.g. older adults, kids, people with disabilities, etc.?

Although the effort for this taxonomy was to simplify the discussion platform, mechanisms behind user acceptance and adoption of the homes and in-home devices are multi-layered which require a deeper understanding of the users. Next research steps can include rounds of thorough reviews with experts in related fields to define evaluative criteria based human preference and performance, a scan of technologies that are available and in development, and a trends analysis to validate and revise the determinative factors across the levels.

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References

1. United Nations Department of Economic & Social Affairs: 2017 annual report on World Population Ageing (2017)
2. Benefield, L.E., Holtzclaw, B.J.: Aging in place: merging desire with reality. Nurs. Clin. **49** (2), 123–131 (2014)
3. Marek, K.D., Rantz, M.J.: Aging in place: a new model for long-term care. Nurs. Adm. Q. **24**(3), 1–11 (2000)
4. Iecovich, E.: Aging in place: from theory to practice. Anthropol. Note-books **20**(1), 21–33 (2014)
5. Roberts, A., Ogunwole, S., Blakeslee, L., Rabe, M.: The Population 65 Years and Older in the United States: 2016. American Community Survey Reports (2018)
6. SAE International: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (2018)
7. GhaffarianHoseini, A., Dahlan, N.D., Berardi, U., GhaffarianHoseini, A., Makaremi, N.: The essence of future smart houses: From embedding ICT to adapting to sustainability principles. Renew. Sustain. Energy Rev. **24**, 593–607 (2013)
8. Mast, M.: User-centered design of a dynamic-autonomy remote interaction concept for manipulation-capable robots to assist elderly people in the home. J. Hum. Rob. Interact. **1**(1), 96–118 (2012)
9. Pilich, B.: Engineering Smart Houses, Lyngby, Informatics and Mathematical Modelling, Technical University of Denmark (2004)
10. Popescu, D., Popescu, S., Bacali, L., Dragomir, M.: Home “Smartness”-helping people with special needs live independently. In: International Conference of Management Knowledge and Learning and Technology Innovation and Industrial Management, Romania (2015)
11. Stefanov, D.H., Bien, Z., Bang, W.C.: The smart house for older persons and persons with physical disabilities: structure, technology arrangements, and perspectives. IEEE Trans. Neural Syst. Rehabil. Eng. **12**(2), 228–250 (2004)
12. Endsley, M.R., Kaber, D.B.: Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics **42**(3), 462–492 (1999). https://doi.org/10.1080/001401399185595
13. Parasuraman, R., Sheridan, T.B., Wickens, C.D.: A model for types and levels of human interaction with automation. IEEE Trans. Syst. Man Cybern. Part A: Syst. Hum. **30**(3), 286–297 (2000)

14. FakhrHosseini, M., Lee, C., Coughlin, Joseph F.: Smarter homes for older adults: building a framework around types and levels of autonomy. In: Zhou, J., Salvendy, G. (eds.) HCII 2019. LNCS, vol. 11593, pp. 305–313. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-22015-0_24
15. Coutaz, J., Crowley, J.L.: A first-person experience with end-user development for smart homes. IEEE Pervasive Comput. **15**(2), 26–39 (2016)
16. Demiris, G.: Smart homes and ambient assisted living in an aging society. Methods Inf. Med. **47**(01), 56–57 (2008)
17. Amiribesheli, M., Benmansour, A., Bouchachia, A.: A review of smart homes in healthcare. J. Ambient Intell. Hum. Comput. **6**(4), 495–517 (2015). https://doi.org/10.1007/s12652-015-0270-2
18. Wilson, C., Hargreaves, T., Hauxwell-Baldwin, R.: Benefits and risks of smart home technologies. Energy Policy **103**, 72–83 (2017)
19. Li, R.Y.M., Li, H., Mak, C., Tang, T.: Sustainable smart home and home automation: Big data analytics approach. Int. J. Smart Home **10**(8), 177–187 (2016)
20. Törnquist, K., Sonn, U.: Towards an ADL taxonomy for occupational therapists. Scand. J. Occup. Ther. **1**(2), 69–76 (1994)
21. Debes, C., Merentitis, A., Sukhanov, S., Niessen, M., Frangiadakis, N., Bauer, A.: Monitoring activities of daily living in smart homes: understanding human behavior. IEEE Signal Process. Mag. **33**(2), 81–94 (2016)
22. Sheridan, T.B., Verplank, W.L.: Human and computer control of undersea teleoperators. Massachusetts Institute of Technology of Cambridge Man-Machine Systems Lab (1978)
23. Riley, V.: A general model of mixed-initiative human-machine systems. In: Proceedings of the Human Factors Society Annual Meeting, Los Angeles, vol. 33, no. 2, pp. 124–128. SAGE Publications (1989)
24. Proud, R.W., Hart, J.J., Mrozinski, R.B.: Methods for determining the level of autonomy to design into a human spaceflight vehicle: a function specific approach. National Aeronautics and Space Administration Houston Tx Lyndon B Johnson Space Center (2003)
25. Beer, J.M., Fisk, A.D., Rogers, W.A.: Toward a framework for levels of robot autonomy in human-robot interaction. J. Hum. Rob. Interact. **3**(2), 74–99 (2014)
26. Sharif, M.H., Despot, I., Uyaver, S.: A proof of concept for home automation system with implementation of the internet of things standards. Periodicals Eng. Nat. Sci. **6**(1), 95–106 (2018)
27. Clark, M., Newman, M.W., Dutta, P.: Devices and data and agents, oh my: How smart home abstractions prime end-user mental models. Proc. ACM Interact. Mob. Wearable Ubiquit. Technol. **1**(3), 44 (2017)