Smart to Smarter: Smart Home Systems History, Future and Challenges

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Abstract

In this paper, we survey smart homes from legacy systems till latest home automation platforms, highlighting the potentials of building technology, and how it might be in the future in designing context-aware and adaptive homes according to users' behavior, instead of solely following pre-defined instructions. We suggest required technologies such as Big Data, IoT (Internet of Things) and extendable wireless sensor-networks in a ubiquitous context-aware environment with the aim of enhancing user experience of Human-Building Interaction. Furthermore, we address few of the major challenges that withhold smart homes from being widely spread. Since the main idea of residential architecture is about ease of use, calmness and adaptiveness to user needs, which all serve neatly with ubiquitous computing concepts. Smart homes should be developed as ubiquitous environments that operate in the background and utilize user's intuitive interactions. Therefore we believe that there is a great potential area of research in human-building interaction in general and context-aware adaptive smart homes in particular.

Author Keywords

Smart Homes; Human-Building Interaction; Embedded Systems; Ubiquitous Computing; Context-awareness; Internet of Things (IoT); Big Data.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

As technology is getting smarter, future buildings are expected to get smarter as well. For decades, researches have been made to augment buildings with embedded systems that enable a multitude of different smart features ranging from energy-management, self-sustainability, security control, entertainment and assisting disabled to the luxury of home automation. Whereas smart-building systems include valuable studies and implementations, fewer research have been held to develop smart systems that are embedded in our daily life as ubiquitous environments to operate in the background without the need of much user intervention, customization and operation. This is not a major problem for office buildings, commercial or executive complexes were there are often dedicated IT specialists administering the 'system'. However, when it comes to home residences, then the main idea of architecture and building structure becomes more about functional ease of use, calmness and adaptivity, which are all suggesting ubiquitous human-building interaction[1]. Smart homes should not only focus on environmental controls for temperature, lighting and shading, but research suggest that home automation and control will become more widespread when adopting an adaptive and context-aware design, potentially embraced by considerable interest in both the architectural and the HCI research community [13].

Background

Smart adaptive homes have been a dream for both architects and system designers in the 20th century. Early trials go back to the 1970s, as a result of technology advancement. Recent advances in embedded systems have enabled some progress in building smart homes and their automation. However, it was expected to see smart homes more widely spread, as smart phones for instance. The term 'smart home' refers to improving home occupant experience using a set of sensors and actuators to observe the environment and automatically control home devices [2]. The term 'home automation' is defined as the capability to automate and control multiple distinct systems [4]. Moreover, we believe that the concept behind smart homes can be perceived as more broader, as it also involves more than just executing instructions, but as further self-learning, the ability of being adaptive and context-aware.

Basically, Smart homes are perceived with three different views: functional, instrumental and socio-technical [16]. The functional view seeks to manage and automate the daily demands in a household in a better way. The instrumental view involves efficient functions such as energy-management and security control. The socio-technical view strives for digitalization of everyday life and opens the door for next generation of human-building interaction[1].

Mozer [11] suggests that a smart home that needs to satisfy users' comfort should include air/water heating, ventilation, and control of both lighting and curtains. However, we believe that the value of home automation is not necessarily from having control over the home as if it was a machine; most of user satisfaction comes from connecting with the home and family [14] so it is very important that the used system has to be hidden enough that doesn't annoy the users or cause any frustration, even that often due to 'over-

smartness' of their home. As technology is developed to empower people, it should not enslave them. In other words, "how smart should be the smart home?!" [12] is an important question.

In general, users who choose to deploy a smart home system often needs to satisfy one of these main objectives [14]: peace of mind regarding home management, optimization and energy efficiency, entertainment or impressing others, personalization, supporting special needs (i.e. disabled or elders), or for religious reasons (e.g. Sabbat home automation [17]).

Smart Home Systems

Legacy smart home automation systems such as X10, Timers and RightSchedule were introduced since 1970s with numerous devices used for security monitoring and control of lighting and appliances, utilizing home existing power line wiring providing simple capabilities that inhabitants often used low-tech solutions to complement them to customize them according to their needs. For example, Jewish families used such automation systems for automating Sabbath rituals (Saturday in Jewish religion) controlling lights and appliances [17].

Lately, researches around smart home automation are taking a different approach providing much more than on/off control. Smart Condo [2] is a smart system used in health care with the aim to support elders and patients, consisting of number of low-power wireless nodes, where each node includes a battery and one or more sensors, such as pressure sensors, read switches and passive infrared motion detectors. The same paradigm can be applied for other purpose by enriching smart home sensor-networks readings using many types of smart sensors such as Zigbee, DMX controllers, and serial protocols devices [8]. On the other hand, ExoBuilding [13] is built as a prototypical piece of architecture that maps a person's physiological data to its building fabric with the aim of understanding the user emotion and accordingly activates the corresponding actuators to act on this emotion.

Conventionally, user interfaces developed to control, administrate and configure/customize home automation systems are desktop, web and mobile applications respectively. However, recent researches have introduced novel ideas including not only mobile apps, but tangibles and wearables as well. Humble's tablet app [7] allows users to connect virtual jigsaw puzzle pieces to configure smart home ubiquitous devices. CAMP [15] enables end-user programming by providing users with a virtual magnetic poetry metaphor to translate their description of an intended behavior into instructions to manage and control their smart homes. Casalendar [9] uses the familiar interface of a calendar in an application to integrate the status of smart home technologies and engage users with their smart home configurations. Likewise, Control Home Easily [8] is a user friendly mobile application that controls home devices using widgets. It is smart enough that it can easily automatically discover the smart devices of the desired room and register them with different hardware technologies. However it allows users to be the administrator, giving them the right to change some rules that may affect others. The same for HBCI (Human-Building-Computer Interaction System) [6] which is an Android mobile application as well that gives the user comfort in addition to saving energy at the same time. It is purely the user decision to activate actuators based on connected sensors by defining a threshold for each sensor. However, it would be of

Figure 1. Wink Smart Home interface [19]

Figure 2. Amazon Echo mic device [17]

Figure 3. Samsung Smart Fridge [18]

great benefit if the system can 'learn' by time the user's preferred decisions and accordingly facilitate for them the routine they need.

Latest examples of smart home automation systems such as Samsung SmartThings [19], Amazon Echo [20] and Flex Wink [20] are competing to provide users with easier and more efficient smart home platforms and/or equipment. Recently, Samsung introduced SmartThings [19] by provided many smart equipment such as sensors, hubs, kits covering many of housekeeping direction's that can open the door for a multitude of innovative applications such as Presence Sensor to give notification of the person present. All can be connected and provide useful support to the inhabitant. Just a few days prior to writing this paper, Samsung announced Samsung Smart Fridge - one of Samsung SmartThings – that include sensors, cameras and 21.5 inch smart touch 1080 pixel screen linked with a mobile app that allows the user to see inside the fridge and support online shopping as well. Amazon Echo [18] is a new speech-based home assistant to be launched soon, equipped with a hi-tech sensitive mic for voice controls even during external noise i.e. playing music. Amazon Echo supports the user by playing music, reading audiobooks and the news, reports traffic and weather. Moreover, it can be integrated with Philips Hue, Samsung SmartThings, Wink, and other smart home devices. Wink [20] is a smart home platform that has a hub, an app for the user interface and a relay with a touch screen controller by which many actuators can be controlled like lighting, dimmers, switches, power outlets, door locks, window treatments and even sprinklers based on sensors covering most of daily activities.

Finally, DOMUS [3] is a lab prototype for future smart homes. It is equipped with 221 basic sensors with 20 RFID antennas distributed to collect data every 20 ms with sensors of data size reached 576 million of data records per day. Data is manipulated with techniques and algorithms to maintain the data and make use of it at maximum. At this stage a new era of adaptive homes that assists users -based on their own previous behavior- is awaiting.

Challenges

In this section we tackle some of the major challenges that withhold smart homes from wide spreading fast enough, as was expected, and face home automation industry and research. We apply some of the seven challenges for smart homes provided by Edwards [5].

Cost Smartness

The first challenge is the high cost of an end-to-end smart home system. It can be the first question the user asks when buying a smart home system before considering its benefits. To bypass this challenge the most balanced solution is to create a resizable/ extendable system by splitting its components into smart cheap equipment that can be included in the system one by one according to user needs and budget.

Expect-ability, Acceptance and Reliability

As people tend to resist change by nature and "enslaving" to a smarter machine [12], installing a new home automation system can be a frustrating challenge, especially for elder users. A smart home system should not be designed as an intruder that may override residents' decisions of lighting, heating and other controls, but should be designed to operate

Smart Homes and IoT: Currently, most smart home systems use M2M concept which does not achieve flexibility or adaptively to fit all homes, where each has its own rules and concerns. Consequently, systems might affect each other or cause user frustrations. By applying Internet of Things (IoT) and Big Data, we can achieve higher performance, efficiency and personalization, saving time and effort as everything will be structured and easily developed and maintained.

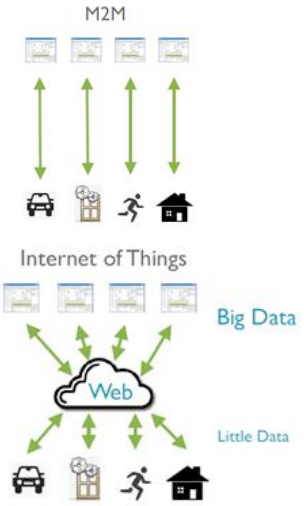

Figure 4. M2M vs. IoT, source:

smoothly and be 'expectable' with minimal accidental surprises [5], to be accepted and embraced by users. This 'acceptance' can be accomplished by answering the basic questions that users tend to be sure about, such as what will this system exactly control? How can I interact with it? Can I have control over it? What is its limitations?[5] Ensuring that smart home users are engaged to understand [9] and probably customize what the system is designed to automate, will have a great impact on people's mindset and acceptance to smart homes. Moreover, smart home devices have to be reliable in all sense and attractive in their physical design as well.

Calmness and Context-awareness

The system that needs frequent administration and maintenance –which most systems do- is not suitable for domestic use. That's why one of the main challenges for smart homes is to be context-aware and adaptive because simply not all residents are do-it-yourselves yourselves and not all residents are following same behaviors. The system has to be user friendly, easy for operation or better be calmly ubiquitous operating in the background. Otherwise it will be frustrating and hence will be disconnected. Moreover the design has to be smart enough in order not to overlap configurations. For example, switching on the lights –which may result some change in home temperature- can unintentionally activate the air conditioner!

Domestic use implications

Designing for domestic use should consider the fact that homes are chaos –if compared with workplaces- and unpredictable to a large extent, especially with the presence of children or more than three residents in one home. Moreover, users should not be expected to have advanced knowledge of technology [5]. Furthermore, it is indeed quite difficult to expect inhabitants' goals [10] depending on hi-tech home automation products without the use of context aware methodologies. As houses and residential buildings are mainly places for living in comfort, adding any discomfort from a system that is less or too smart than needed is not desired at all.

Architectural Readiness

One of the obstacles for adopting smart homes is whether it's better for a house to be augmented with smart devices or it should be built smart from the first place. Some believe that smart home design should start with the architectural schematic phase of building the house, involving all concerned parties: project owner, architect, embedded system designer and user. While others believe that any pre-existing building can still benefit from smart equipment that can be purchased and connected even on phases.

Conclusion

In the last few years, smart homes are beginning to take a new approach of wireless sensor platforms connected to mobile apps relying on IoT rather than M2M wired embedded sensors that require expensive pre-installations. We believe that in 2030, with more human intelligence and awareness of sustainable home design, embedded systems should be context-aware, adaptive to user behavior and living patterns using ubiquitous computing; Big Data & extendable sensor-networks to achieve both user-friendly and socio-economic smart homes.

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[19]Samsung SmartThings. https://www.smartthings.com/uk. Samsung.

[20]*Wink: A Simpler Way to a Smarter Home. www.wink.com*.