

The eHome – a Practical Smart Home Implementation

Lasse Kaila, Jussi Mikkonen, Antti-Matti Vainio, Jukka Vanhala

Tampere University of Technology, Department of Electronics
Korkeakoulunkatu 3
33720 Tampere, Finland
Tel. +358 3 3115 11, fax. +358 3 3115 3394
{lasse.kaila, jussi.mikkonen, antti-matti.vainio, jukka.vanhala}@tut.fi

Abstract. The eHome project was started in order to find out how a smart home would perform under normal everyday conditions. A network of ubiquitous devices and user interfaces were installed in a regular 52 m² apartment, where two young people lived and used the equipment in their everyday lives. The goal was to study what a smart space should contain and how users can interact with all the equipment. Emphasis was placed on practicality and user studies. This paper describes the motivation, implementation and results of this three-year research project.

1. Introduction

Smart homes and environments have been discussed and hyped for many years now [1], and despite technological advances, future visions and dreams the concept of a smart home remains distant and unfamiliar. To the average citizen it is not clear what a smart home actually is, and even among professionals the definition of a smart home varies depending on whom you ask. Thus it is not surprising that smart homes are still waiting for their breakthrough on the common market. Still, with electronic devices and appliances becoming more and more numerous and common in everyday life it would be beneficial to have an easy way to control and interact with all these. This is possibly one of the biggest assets a smart home could have. Instead of running theoretical tests, simulations and laboratory experiments we saw a need to investigate to how a smart home would function in everyday life. The eHome project was a three-year study on how devices, networks and user interfaces (UIs) work together in everyday life in a normal home environment.

2. Motivation

Smart homes, ubiquitous computing and home networks have been popular research topics over the years [2,3], but practical applications are still rare or nonexistent. There really is not much knowledge of how smart homes would work in practice, when dealing with everyday life. Many smart spaces that exist today are corporate

showrooms, design showcases or laboratories that have been made to resemble normal homes, decorated with modern furniture and filled with modern gadgets [4]. A common problem with many applications is that control is very restricted and devices do not have much knowledge about what is going on elsewhere in the network. There is no “intelligence” in the system, not to mention that the price for such a system is very high [4]. The technology has been advanced enough for decades, but there seems to be something essential missing, either from an application or a technical point of view, that would make people want to have smart homes [5]. In order to bring the technology and applications available for everyone the price has to go down and usability and value to normal living has to increase considerably. Modern homes are already being equipped with more and more electronic devices and appliances, each with their own UI and operational logic. Learning to use all the user interfaces of all possible appliances at home can be a tedious task [6], but with a centralised and intuitive UI these problems might be alleviated. In addition, it is possible to tailor the UI to better suit the needs of the current group of users, or even individuals. This reason alone is why we feel that smart homes could really offer people additional value and increased usability.

The Personal Electronics research group has been involved in smart home research since 1999, and a few smart spaces had already been constructed before the eHome. The Living Room was a former laboratory converted into a living space with a living room, kitchen and a small hall. It was used for testing the first infrastructure and user interface prototypes. A few years later a complete apartment, Smart Home, was built at the university. It was designed to be a flexible, versatile testing space with removable floor and ceiling tiles, customised electrics and lots of space for equipment. The Smart Home was fitted with devices similar to the ones in the Living Room, plus an upgraded communications network, more UIs and new adaptive and learning control software.

With these thoughts in mind we decided to run a new research project parallel to the Smart Home. In contrast to laboratory and theoretical tests, empirical testing in a real home and a real-life everyday scenario would provide extremely valuable feedback and results. In the eHome-project we wanted to investigate what kinds of ways there were to interface with home devices, electronics and functions and how these would work in practice. Also other advantages that a smart home can offer, like increased security and safety by monitoring both appliances and people, lower energy consumption by turning off lights and unused equipment, were interesting [7].

3. The eHome

The eHome is a 52 m² flat, with a bedroom, living room, kitchen, sauna and bathroom. The apartment and network infrastructure can be seen in Figure 1.

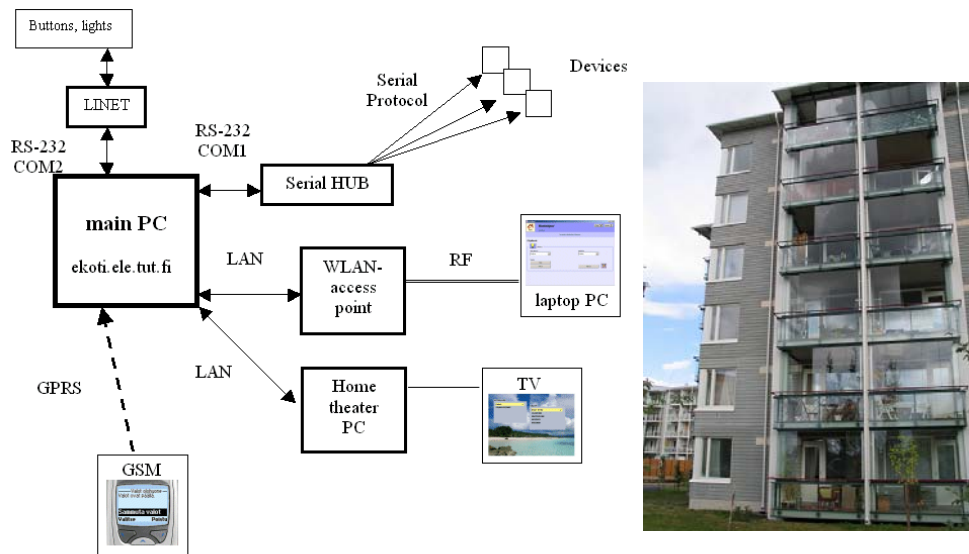


Fig. 1 Network infrastructure of the eHome, showing networked devices, networks, user interfaces and the server. The apartment itself is shown on the right-hand side.

The apartment was fitted with an appropriate infrastructure in order to create a network for all installed devices and home appliances. Both wired and wireless technology was used, making mobile applications also possible. Control networks exist for both mains (230 VAC) and lower voltages, and they cover the entire apartment. In order to be able to connect devices, UIs and sensors together most of them had to be custom built at the university. Functionality was also added to commercial devices where possible and a simple communication protocol was created in order to standardise functions and messages in the home network. A standard PC was chosen to function as a network master, since a modern PC already contains several kinds of network connections. The PC was connected to the home networks controlling the devices, and it also had an Internet connection and functioned as a web server. It ran a Java software package called the Home Controller, which was responsible for all functionality in the eHome, devices and user interfaces. Using software modules it was basically possible to use any network types, as long as they could be connected to the PC.

The eHome featured motorised window blinds, lighting controls (on/off, dimming), universal infrared remote controls for A/V equipment, controllable mains sockets etc. Home appliances such as stoves and microwave ovens were not included directly in the home network because they lacked a common control interface. Monitoring and measuring them externally however was possible. Sensors measuring temperatures, humidity levels and current consumption were also used to detect various changes in the apartment, such as windows or doors that were accidentally left open. In order to be able to control and monitor all these devices and home electronics the eHome

featured both mobile and static UIs. This way users had flexible control of the home and we were able to find out the usefulness and usability of each UI. User interfaces in the eHome included a mobile phone (for both local and remote connections), a web-based UI (which could be used from a touch screen-equipped laptop PC) and a TV UI (mimicking a digital set-up box). Each UI had its own purpose and different adjustable functions, designed to complement each other. The web UI was designed to be the most versatile UI, and it allowed users to control all devices and also make timer settings and different preset modes.

Two tenants, a male/female couple (a cultural historian and a biologist), in their mid-twenties, were selected to live in the apartment for a period of three years. During this time they reported their experiences with the smart home systems, user interfaces and daily routines. A usability researcher was present each time a new UI was introduced or when regular feedback was collected.

4. Findings and lessons learned

During their three-year period the tenants gave the usability lab a lot of material to study and digest. When the project was concluded user feedback was collected and analysed [8]. It was interesting to see how living in the eHome had changed the tenants' daily routines, how visitors to the eHome experienced it and how the system performed as a whole. In the beginning of the testing period the tenants naturally had their suspicions about the system and its reliability. It took a few weeks for them to get used to using everything and learning how to operate the different user interfaces. New UIs and functionality was introduced to them gradually, and every time a new device or function was added the same learning process was repeated. In spite of what the tenants thought in the beginning, the mobile phone had become by far the most popular UI. The tenants had no more worries about having forgotten to turn off the lights or the coffeemaker, and usually pressing a few buttons on the phone is a lot quicker than turning on the laptop PC or TV just to make one quick adjustment. The mobile phone is also easy to carry with you, it is always on and the user interface is familiar to everyone [8]. The tenants also appreciated the different timer and mode settings that the web-UI offered. Instead of waking up in the morning to a ringing alarm clock they set the window blinds to open and bedroom light to turn on in the morning, creating a more natural way of waking up. Programmable wall switches were also convenient for grouping lighting controls and turning all lights off from a single button. The TV UI was not as popular, as using it might interrupt the TV programme and annoy other viewers. In a nutshell, every UI had its strengths and weaknesses, and using multiple UIs instead of one single UI also provided flexibility and new possibilities. However in the future mobile phones may soon overtake an important role as primary smart home UIs.

The eHome system was running continuously for three years, and the infrastructure itself worked appropriately throughout the experiment. There were no hardware faults apart from a few blown fuses and a broken light dimmer. The biggest downtimes were caused by software updates, bugs in the Home Controller software and network failures. If there was a technical problem and a UI was not functioning for a while it

was not such a big deal, the tenants simply stopped making more complex adjustments for a while and used traditional manual controls instead. However sometimes it took many days for them to start trusting eHome UIs again after a problem had occurred. Also if there was a network problem and a device could not be adjusted remotely the users thought it to be very annoying. It was also very difficult for the users to locate the fault, which in turn increased the feeling of frustration.

The eHome taught us a lot about practical issues around smart homes. The increasing amount of technology and complexity in our lives can lead to worries about losing control [3]. In the eHome, for example, the users were worried about forgetting to turn off home appliances when they left the home. The female tenant even had a habit of unplugging everything that was not used when going away for a few days; she was worried about possible fire risks. Once before in her previous apartment she had accidentally unplugged the freezer, which of course resulted in lots of spoiled food. A temperature sensor inside the freeze would have warned about this. The eHome tenants were thus happy about having the possibility to monitor and turn off equipment remotely, it increased their feeling of security. Remote control of lights and appliances can also help in reducing energy usage, especially if heating could be controlled. The tenants also commented that a future smart home control system should contain some kind of adaptivity and proactivity. The eHome implementation did not learn new rules and behaviour on its own, it had to be pre-programmed or set by the users. Furthermore, the tenants also pointed out that it is not desirable to have an automated home with things happening without any influence from the users. Instead it is important to let users have control, or at least a sensation of being in control of the networked devices. On the other hand, constantly having to adjust or control something is not desirable either, which leads to quite a controversy [5]. A proper solution might be a home controller with a certain degree of automation, which could be overrun and set by the users. Additionally the tenants saw the implemented system slightly limited as far as its capabilities were concerned. More adjustable devices, features and sensors would have increased the usefulness of the eHome system.

5. Smart Home Challenges

The biggest challenge smart home researchers face is the lack of standardised or completely missing communication interfaces in home electronics. This problem can be alleviated by using adapters and converters, however there are limits on what each interface can do and usually some functions remain unavailable. Another practical obstacle becomes obvious when installing networks and devices in older buildings. Even wireless networks require power cabling, and equipment need their own installation space. In cases like these it is advantageous to use existing cabling (phone and power lines, cable ducts etc.) as much as possible. For energy savings control of heating, ventilation and air conditioning (HVAC) would be a must, unfortunately in most apartment buildings it is not possible to sufficiently affect the temperature inside a single apartment or even in a room. Problems regarding how adding new devices should be worked out depend largely on the infrastructure used. In a proprietary

customised network it might require large modifications to the infrastructure and UIs in order to fully utilise the new device. Even if the protocol and network would support on-the-fly addition of devices the biggest challenge lies in creating dynamic UIs that automatically change when changes have been made in the infrastructure. Service discovery protocols, plug-and-play networks and dynamic UIs are a viable but extremely complicated solution to this problem.

When considering a scenario like the eHome, where prototype devices have to work 24/7 we also have to think about reliability and software stability issues. If a device malfunctions, a fuse is blown or the control software crashes how can the problem be fixed? In what way does it affect the functionality of other devices, and how quickly can it be repaired? The inhabitants have also got to be taken into account, as their lives should be as unaffected by these possible faults as possible. Some problems can be solved by a simple flip of a circuit breaker or a reset button, but in worse situations someone has to go over and perform repairs. With a remote connection to the eHome it was possible to remotely switch off relays and thus reset devices, as long as the Internet connection was up and running. The tenants were also able to reset the server in case of a hardware/software crash, but more involvement in the debugging process was not desired or allowed. A question of reliability also surfaces, because even today's technology that is rushed onto the market is largely untested, barely working and usually needs software updates right from the start. How can users cope with these kinds of problems if they continue to spread to home appliances and control systems? This might require third party services, possibly a caretaker or support company that assists users providing smart home services and support.

From a human point of view the concept of smart homes is rather unfamiliar to the average user [7] and this, together with new technology, often leads to suspicions and prejudices. The home is also considered a very private and personal environment, and ubiquitous electronics and sensors that monitor and make adjustments can be seen as intrusive [9]. The issue around privacy is a difficult one to tackle, even physically hiding or embedding sensors will not help if the users know that they are being monitored in some way.

6. Conclusion

The eHome project was a unique study, which concentrated on finding out how a smart home would function in everyday life and what kinds of functionality it should provide to its users. This practical study revealed results that would not have been discovered in theoretical laboratory tests. It would seem that the most desirable functions of a smart home are indeed various user interfaces that allow more flexible control of the home. The home should also contain learning and adaptive functions, which would gradually allow users to leave some functions to the Home Controller. However as long as there are no compatible devices on the market it seems that there is a long way to go before smart homes really become commonplace. After the eHome the development of smart homes still continues at the university Smart Home lab in the form of a proactive, adaptive space.

About the author

Lasse Kaila started working with smart spaces and devices at the Institute of Electronics in 1999. He received his Master's degree from Tampere University of Technology in 2001 and he is currently writing his PhD thesis on smart home implementations. He has a background in electronics design, embedded devices and personal electronics.

7. References

- [1] R. Harper : Inside the Smart Home, Springer verlag, 2003, 264 p.
- [2] C. D. Kidd et. al. : The Aware Home: A Living Laboratory for Ubiquitous Computing Research. Proceedings of the Second International Workshop on Cooperative Buildings, CoBuild'99, 1999.
- [3] Mozer, M. C., Lessons from an adaptive house. In : Smart environments: Technologies, protocols, and applications, pp. 273-294, 2005.
- [4] Philips Research, What is Ambient Intelligence?, (March 2, 2004), Available at http://www.research.philips.com/technologies/syst_softw/ami/index.html [Accessed: August 20, 2007].
- [5] F. K. Aldrich : Smart Homes, Past, Present and Future. Inside the Smart Home, 2003, Springer, London.
- [6] W. Green, D. Gyi, R. Kalawsky, D. Atkins : Capturing user requirements for an integrated home environment. Proceedings of the Nordic conference on Human-Computer Interaction, NordiCHI '04, Tampere, Finland, October 23-27, 2004.
- [7] S. Leppänen et.al. : Smart Home, from pilot to mass product (in Finnish), TEKES project report, 2004.
- [8] T. Koskela, K. Väänänen-Vainio-Mattila : Evolution towards smart home environments: empirical evaluation of three user interfaces. Personal and Ubiquitous Computing, 2004, Volume 8, Issue 3-4, pp. 234 – 240.
- [9] F. Mäyrä, A. Soronen, J. Vanhala, J. Mikkonen, M. Zakrzewski, I. Koskinen, K. Kuusela : Probing a Proactive Home : Challenges in Researching and Designing Everyday Smart Environments. Human Technology, 2006, volume 2, pp. 158-186.